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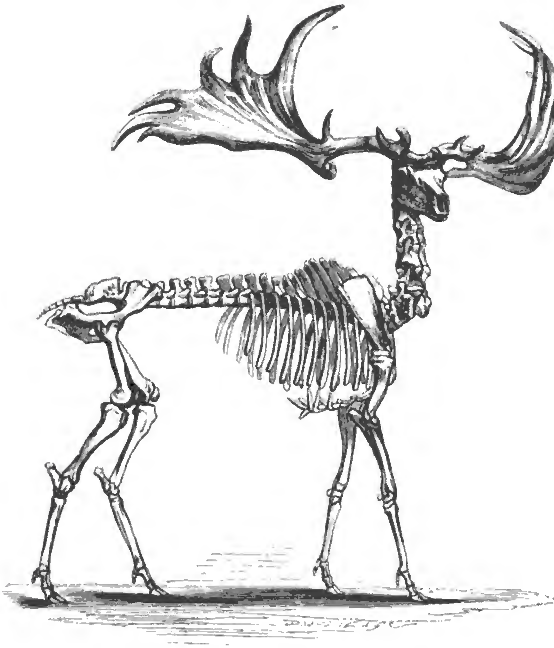
STUDENT'S MANUAL OF GEOLOGY.



MEGACEROS HIBERNICUS.

(The Irish Bighorn.)—See p. 685.

This cut and the one on the title-page are borrowed from Owen's Palæontology.

THE

STUDENT'S MANUAL

OF

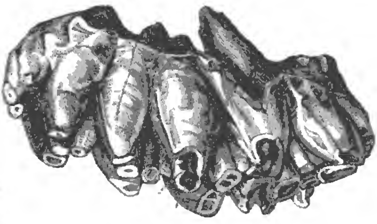
GEOLOGY

BY

J. BEETE JUKES, M.A., F.R.S.

LOCAL DIRECTOR OF THE GEOLOGICAL SURVEY OF IRELAND, AND LECTURER ON GEOLOGY TO THE MUSEUM OF IRISH INDUSTRY.

A NEW EDITION,
PARTIALLY RECAST, AND SUPPLIED WITH LISTS AND FIGURES OF CHARACTERISTIC FOSSILS.



UPPER MOLAR OF MASTODON ARVERNENSIS.

EDINBURGH:
ADAM AND CHARLES BLACK.
1862.

PRINTED BY R. AND R. CLARK, EDINBURGH.

PREFACE TO SECOND EDITION.

I HAVE endeavoured in this Second Edition of the Student's Manual to come a little closer to my original conception than I was able to do in the first.

I have to renew my acknowledgments to my colleague Dr. W. K. Sullivan for assistance in the part devoted to Chemistry and Mineralogy. Since that part was printed off, the Glossary of Mineralogy by another old colleague, Mr. W. H. Bristow, has been published, a little work which the student will find most useful to him. Its late appearance prevented me from availing myself of it except in the compilation of the index.

In the other portions of the part which is entitled Geognosy I have tried to improve the arrangement in some places, and in others have introduced some new matter, such as the chapter on Orography. The part relating to mineral veins and mining has been kindly

looked over by my old colleague Mr. Warington W. Smyth.

An interesting and instructive work on the lead mines of the Alston Moor district, entitled, "The Laws which regulate the deposition of Lead Ore," has since been published by Mr. W. Wallace, which the student will find an important contribution to our knowledge of this subject, and one directing his attention into what I believe to be the right direction.

My colleague Professor Huxley has again afforded me his valuable help in the classification of the Animal Kingdom, and I am also indebted to the books and the advice of Professor Reay Greene on this part of the subject.

By the liberality of the publishers I have been enabled to take advantage of the presence of Mr. W. H. Baily in Dublin, who compiled for me lists of characteristic fossils, which, with some modifications, are those given in the third part of the work. Mr. Baily also drew on the wood the figures which make the fifty "fossil groups" by which that part is illustrated. To the names of the fossils which are not figured in them, I have appended references to figures in other works, choosing, where I could, the most popular books, such as Lyell's and Phillips's Manuals, and the Tabular View of Characteristic British Fossils pub-

lished by the Christian Knowledge Society; but where no figures exist in such works, I have referred to more recondite sources, such as the publications of the Palæontographical Society, Sowerby's Mineral Conchology, Sir R. I. Murchison's Siluria, and others. Morris's Catalogue of British Fossils has necessarily been my chief guide in selecting these references with respect to all Post-Silurian fossils, the catalogue by Morris and Salter in the last edition of "Siluria" taking its place for those of the previous periods.

I am indebted to my colleague Mr. G. V. Du Noyer for some sketches, and for the drawing of some of the diagrams, but most of the latter were drawn by myself, which will in great measure account for the roughness of their execution. This roughness, however, is not altogether undesigned, since I wished to make them just such figures as a lecturer would draw on his black board, and not to lead the student to believe from any care discernible in the drawings, that they were intended for actual representations of existing objects. A diagram is merely a condensed explanation addressed to the mind through the eye, instead of through the ear. If it is intelligible, and assists the verbal description, it answers its purpose; it is a mistake to endeavour to convert it into a picture, and it is better to avoid anything

calculated to mislead the mind into the supposition that it would have been one if the draughtsman could have made it one.

In drawing up the Index I have followed the example of Professor Owen in the index to the second edition of his Palæontology, and given the explanation of words derived from the Latin and Greek. I have also marked the pronunciation of such words as could possibly require it, by means of the long (-) and short (˘) marks commonly used to denote the quantity of vowels.

In a science of pure observation like Geology, in which the facts to be observed are of so many different kinds, and where so many observers are at work all over the world, constant progress must necessarily be made, as well as continual correction and improvement.

Any one, therefore, who endeavours to give even so slight and general a sketch of it as is contained in this Manual, will not only find that much change has taken place in it in the interval between the renewal of his attempts, but that some, perhaps important, alterations are going on while he is in the very act of writing.

The student, however, will find, I hope, no important part of the science entirely neglected in the

work now placed before him, and something in each part that may serve to lay the foundation of his future studies.

I beg leave to add that any criticisms which serve to correct errors will always be taken as favours, whether publicly or privately made. I have discovered some mistakes myself while going over the work for the purpose of compiling the index, and pointed them out in the "errata." Others probably exist which have escaped my eye, independently of those arising from imperfect knowledge, or from incorrect views.

J. BEETE JUKES.

CONTENTS.

SECTION II.—PETROLOGY.

PART II.

PALÆONTOLOGY.

* I unfortunately omitted to mention the occurrence of these gravel ridges in Scotland, where they are called "Kames," according to Mr. R. Chambers. One was described by Mr. Milne Home at the meeting of the British Association in Manchester in the year 1861.

ERRATA.

Page 394. Line last, for Æpyronis, *read* Æpyornis.
478 and 479, for Palæochoma, *read* Palæocoma.
501. Line first, for perosa, *read* porosa.
504. Line 11 from bottom, for Proteus, *read* Proetus.
530 and 536. For Bellinurus, *read* Belinurus.
535. For Næggerathia, *read* Nœggerathia.
536. For Littorina, *read* Litorina.
536 and elsewhere. For Cælacanthus, *read* Cœlacanthus.
543. For Polycælia, *read* Polycœlia.
550. Line 7, for Lilliiformis, *read* Liliiformis.
560. Line 12, for Lilly, *read* Lily.
578. Line 21, for Corraline, *read* Coralline.
584. Line 4, for argustus, *read* angustus.
594. Line 13 from bottom, for Astrocænia, *read* Astrocœnia.
594. Line 12 from bottom, for Enallohælia, *read* Enallhelia.
594. Line 9 from bottom, for Placosphyllia, *read* Placophyllia.
594. Line *ib.* from bottom, for Pleurocænia, *read* Pleurocœnia.
595 Line 13, *dele* Galeropygus.
595. Line 4 from bottom, for Tetrosternon, *read* Tretosternon.
599. Line 28, for Copolites, *read* Coprolites.
611. Line 7, for intermedius, *read* attenuatus.
630 and elsewhere. For termination cænia, *read* cœnia, as it apparently refers to the common body, or κοινον.
631. Line 10 from bottom, for Decretis, *read* Dercetis.
646 and 649. For Lymnæa, *read* Limnæa.
653. Line 26, for Ætobatis, *read* Aëtobatis.
668. Among the Polyzoa insert
Fascicularia aurantium . . . . Ly. Man., fig. 154.
669. From the *Actinozoa* remove Echinocyamus and place it on next page under *Echinodermata*.

INTRODUCTION.

It is not easy to give an accurate and comprehensive definition of the science of Geology; for its nature is so complex and various, that it is difficult, in a few words, either to specify its object or to assign its limits.

It is, indeed, not so much one science, as the application of all the physical sciences to the examination and description of the structure of the earth, the investigation of the processes concerned in the production of that structure, and the history of their action.

We might, perhaps, without impropriety, classify all the physical sciences under two great heads, namely, Astronomy and Geology. The one would comprehend all those sciences which teach us the constitution, the motions, the relative places, and the mutual action of the Astra, or heavenly bodies; while the other singled out for study the one Astrum on which we live, namely, the Earth.

Giving this wide meaning to Geology, it would include all the sciences which treat of the nature and the distribution of the inorganic matter of our globe, as well as those which describe to us the living beings that inhabit it. These sciences are—first, that of Chemistry and Mineralogy (which may be called one), which teaches us what are the elements of which terrestrial matter is composed, and what are the laws which govern the combinations of those elements into all the variety of known substances, solid, fluid, or gaseous, and the forms, properties, and qualities of those substances; secondly, the science of Meteorology and Physical Geography (which may also be looked on as one), which describes to

us the form and disposition of land, and water, and air, and the distribution of the temperatures and motions that affect them ; and thirdly, that of Natural History (or Biology, the science of life), including botany and zoology in their widest signification.

The sciences commonly included under the head of Physics, those which teach us the nature and laws of magnetism, electricity, light, heat, force, and motion, would be common ground to Geology and Astronomy, serving to bind together all human knowledge of matter and its laws into one great whole.

In giving this high place to Geology, I have no desire unduly to exalt it at the expense of the other sciences. My object is to shew that this large view of Geology is not only a true, but a necessary one, and that if we do not sometimes look at it from this aspect, we cannot rightly understand nor fully appreciate what Geology is.

That it is true, is shewn by the very fact of the late appearance of geology in the world of science. It was not till some very considerable advances had been made in all the physical sciences which relate directly to the earth, that geology could begin to exist in any worthy form. It was not till the Chemist was able to explain to us the true nature of the mineral substances of which rocks are composed ; nor till the Geographer and the Meteorologist had explored the surface of the earth, and taught us the extent and the form of land and water, and the powers of winds, currents, rains, glaciers, earthquakes, and volcanoes ; nor till the Biologist (naturalist) had classified, and named, and accurately described the greater part of existing animals and plants, and explained to us their physiological and anatomical structure, and the laws of their distribution in space ;—that the Geologist could, with any chance of arriving at sure and definite results, commence his researches into the structure and composition of rocks, and the causes that produced them, or utilise his discoveries of the remains of animals and plants that are enclosed in them. He could not till then discriminate with certainty between igneous and aqueous rocks, or between living and extinct animals, and was therefore unable to lay down any one of the foundations on which his own science was to rest.

Neither would it be satisfactory if we were to limit the science of Geology to any period of the earth's history; to assign to it, for instance, all time previous to the existence of the human race, and were to unite all the natural sciences under it up to that time, but then consider it to be brought to an end, or to split up and diverge into the many independent sciences that concern our cotemporary existences, whether organic or inorganic. For not only is there no trace of any hard boundary line between the human and the pre-human period of the earth's natural history; but there appears in each one of the separate natural sciences a perfect blending and continuity from the remotest geological era to the present time. The present is but a part of the past. The inorganic objects we see around us are the result of processes going on in past time, such as are still at work producing the same results; the living beings around us are either the direct descendants of those that lived formerly, or their substitutes and representatives, the living and the extinct forming parts of one great connected series and chain of species, genera, and orders, each of which parts would be incomplete without the other. There is, therefore, no possibility of making any division in geology such as we are now considering it, or assigning any limit to its range from the earliest period of the earth's ascertainable history to the present moment.

Moreover, as there is no natural science to which the geologist has not to appeal for information upon some point or other in his researches, so there is none which can be fully and completely studied without the help of the geologist, or without including facts or theories which are commonly and rightly reckoned parts of his peculiar intellectual domain. If he has to call upon the professors of each one of the physical sciences in turn, for assistance in his own investigations, he is sure, sooner or later, to repay the obligation, by the discovery of a number of facts that enlarge the boundaries of the science he has applied to, or by the statement of many problems whose solution throws light upon parts of it that have been hitherto imperfect and obscure.

The reader must not infer from what has been said, that in

order to be a geologist, he must be thoroughly acquainted with the whole circle of the physical and natural sciences. Such universal acquirement few men have the power to attain to, and of these still fewer retain the ability and the will to make original advances in any particular branch.

No man, however, can be a thorough geologist without being acquainted, to some extent, with the general results of other sciences, and being able both to understand them when stated in plain untechnical language, and to appreciate their application to his own researches. Such a general acquaintance involves neither profound study, nor requires any great power of mind above the average of human intellect. It is, indeed, what every well-educated man ought to possess.

The necessary preliminary to the science of Geology is not the possession of great and accurate knowledge of the whole circle of the natural sciences by any individual persons, but that this knowledge must exist somewhere. Some man or men must have this knowledge, and must be able to combine it, either piecemeal or at once, with the special knowledge of the geologist, before the latter can hope to solve the many difficult and profound problems that arise in the course of his researches.

It may be said with perfect truth, that the geologist is less able than any other student of science to pursue his investigations alone, and independently of the assistance of others ; but this is, in fact, only saying in other words that which I am insisting on, namely, that geology in its highest and widest sense embraces all the physical and natural sciences, and is, as it were, made up of them.

If, however, this wide scope be properly given to the term geology, and it be made to include every physical science that treats of anything belonging to the earth, what, it may be asked, is the special business to which the geologist devotes himself as distinct from the follower of other sciences ? What is that which he does, and the others do not ? Above all, what is that which he teaches to the rest in return for the knowledge communicated to him ?

The answer to these questions will shew us that there is another and a more restricted sense of the word geology than the wide and general one in which we have been using it. This sense is rather the one formerly attached to the word geognosy, by which we may understand the knowledge of the nature and position of the different masses of earthy or mineral matter of which different districts and countries are composed, without reference to the history of their production. This was the early and simple meaning of the word geology, or geognosy, namely, the examination and description of the different varieties of rocks and the minerals they contained. Geology was looked upon in the light of a geographical mineralogy, and even yet it is regarded more or less under this aspect by many persons. No one, indeed, could have anticipated, from the mere study of masses of stone and rock, where, to a partial and local view, all seems confusion and irregularity, the wonderful order and harmony which arise from more extended observation and the almost romantic and seemingly fabulous history which becomes at length unfolded to our perusal. To discover the records on which this history is founded, and to understand their meaning aright, frequent, long-continued, and wide-spread observation and research in the field, and patient and conscientious registration and comparison of the observed facts in the closet, are absolutely necessary.

The collection and co-ordination of these facts is the proper and peculiar business of the geognost. The ditch, the "cutting," the quarry, and the mine, the cliff, the gully, the mountain-side, and the river-bank, are his "*subjects*," that which he has to study, to examine, to dissect, to describe the minutiæ of the structures they expose, and to classify and arrange the facts they may afford, depicting their lineaments on maps and sections, and recording them in written descriptions. The business of the geognost, then, is to make out, from indications observed at the surface and in natural and artificial excavations, the internal structure, the *solid geometry*, of district after district, and country after country, until the whole earth has been explored and described. If, while so

doing, he notes all those facts which may enable him or others to understand and explain how that structure has been produced, he then becomes a geologist.

It might at first be thought that in order to make out the solid structure of lands and countries it would only be necessary to understand the nature of the mineral matters of which they were composed, and that for this purpose no knowledge of organic or living beings would be required. It is, however, one of the most remarkable results of geological science that an acquaintance with organic, and especially with animal forms, is at least as necessary for a geologist as a knowledge of minerals, and that a correct knowledge of organic remains (portions of fossil plants and animals) is a more certain and unerring guide in unravelling the structure of complicated districts than the most wide and general acquaintance with inorganic substances.

The cause of this necessity, puzzling and paradoxical enough, perhaps, at first sight, may be briefly stated as follows. When we come to examine the structure of the crust of the globe we find that its several parts have been produced in succession, that it consists of a regular series of earthy deposits (all called by geologists rocks) formed one after another during successive periods of time, each of great but unknown duration. Now, the mineral substances produced at any one period of this vast succession of ages do not appear to have had any essential difference from those formed under like circumstances at another. We cannot, therefore, with any certainty discover the order of time in which the series of rocks was formed, or the order of superposition which they consequently preserve with regard to each other, from an examination of their mineral character or contents only. The animals and plants, however, living at one period of the earth's history were different from those living now, and different from those living at other periods. There has been a continuous succession of different races of living beings on the earth following each other in a certain regular and ascertainable order, and, when that order has been ascertained, it is obvious that we can at once assign to its

proper period of production, and therefore to its proper place in the series of rocks, any portion of earthy matter we may meet with containing any one, or even any recognisable fragment of one, of these once living beings.

Just as when we find under the foundation-stone of any ancient building a parcel of coins of any particular sovereign, we know that the erection of that building took place during his reign, so when we find a fragment of a known "fossil" in any piece of rock, we feel sure that that rock must have been formed during the period when the animal or plant of which that fossil is a part was living on the globe, and could not have been formed either before that species came into existence, or after it became extinct.* In cases, therefore, where the original order of the rocks has been confused by the action of disturbing forces, or where the rocks themselves are only at rare and wide intervals exposed to view, their periods of deposition and consequent succession in superposition may be more easily and certainly ascertained by the examination and determination of their fossil contents than by any other method.

Practically, it has been found that while a very slight acquaintance with the most ordinary forms of some ten or a dozen of the most frequently occurring minerals is all that a geologist must *inevitably* learn of mineralogy, the number of fossil animals and plants, with the forms and the names of which he will have to make himself familiar, will often have to be reckoned by hundreds.

This branch of geological knowledge is now known under the name of Palæontology.

Perhaps, however, the tendency of late years has been to neglect to too great an extent the bearing of mineralogical knowledge on geology. There are many subjects on which we have still to ask the chemist and mineralogist to enlighten us.

One deficiency which is particularly obvious in Britain is the want of a good and precise nomenclature of rocks, and especially of

* The very rare and exceptional cases in which ancient coins *may* have been deposited in the foundation of a recent building, or fossils originally in one rock may have been washed out of it and buried in another, need not more than a passing notice.

igneous rocks. Since the publications of Jameson and Maculloch, no attempt has been made in English to supply this deficiency, and to bring up our lithological nomenclature to the present state of chemical and mineralogical knowledge. Several works, however, have lately appeared in German, which have treated the subject of rocks more or less satisfactorily, as those of Nauman, of Bernhard Cotta, and of Senft. These works have been consulted, and some of their matter used in the lithological descriptions introduced into this work, while their arbitrary classification and arrangement of rocks has been made more simple, and, as appears to me, more natural.

Distribution of the Subject.

In order to reduce the great subject of geology to something like order, it appears advisable to divide it into three heads, for which we may use the terms—1, Geognosy ; 2, Palæontology ; and 3, The History of the Formation of the Series of Stratified Rocks.

This will enable us to describe separately those general facts in structure which either are or may be common to the rocks of all ages, and those general laws which regulated the distribution of life in all epochs of the world's history, and leave us free to give a condensed statement of the third part without stopping to describe special instances of general facts.

By Geognosy I would understand, then, the study of the structure of rocks independently of their arrangement into a chronological series, and I would divide it into two parts—Lithology and Petrology. By Lithology I would mean the study of the internal structure, the mineralogical composition, the texture, and other characters of rocks, such as could be determined in the closet by the aid of hand specimens.

Under Petrology I would arrange the larger characteristics of rocks, the study of rock-masses, their planes of division, their forms, their positions and mutual relations, and other characters

that can only be studied in "the field," but without entering on the question of the geological time of their production.

Under the head of Palæontology I should wish to give the heads of several great questions as to the laws which have governed the distribution of life both in space and in time, as also to indicate some of the chief points in the structure of the more important extinct races, and their relations to those now living. I shall also endeavour to point out the practical bearings of this subject, both scientific and economical.

Having thus described under separate heads facts and generalisations common to the whole subject, and structures and phenomena which may recur during every geological period, I shall, under the head of "History of the Formation of the Crust of the Globe," give a condensed abstract of that history, in the form of a chronological classification, mentioning some of the principal and typical groups of rocks known to have been produced, and a few of the more common and best marked fossils which lived at different parts of the earth during each of the known great periods of its existence.

PART I.

GEOGNOSY.

SECTION I.—LITHOLOGY.

CHAPTER I.

CHEMISTRY AND MINERALOGY.

LITHOLOGY, or the study of the mineral structure of rocks, is based on mineralogy. For a knowledge of mineralogy the student must have recourse to special works upon the subject, as for instance to those of Nicol, Dana, Phillips, Miller, Brooke, and Mitchell and Tennant. But for the proper understanding of mineralogy, some knowledge of chemistry is essential. This must be gained, not only from books, but from study in the laboratory. Gmelin's Handbook, translated for and published by the Cavendish Society, contains, perhaps, the most full and accurate details on the chemical part of mineralogy.

In order to understand lithology, however, an acquaintance with the whole science of mineralogy, though always useful, is by no means necessary, since the minerals which are the essential constituents of rocks are very few compared with the whole number of minerals. There are two methods of studying mineralogy, one giving principal attention to the external characters and physical properties of minerals; the other, laying most stress on their internal chemical composition. The former gives us the readiest means of determining the different kinds of minerals, but for investigating the mineralogical constitution of rocks, the latter is the more important of the two, since it teaches us not only what the minerals are, but how they were produced. It is,

therefore, absolutely necessary to understand so much of chemical nomenclature and chemical laws as shall enable us clearly to comprehend the precise meaning of the terms describing this chemical composition.

As, however, geologists, from the very nature of their pursuits, are unable to devote much of their time to closet study or laboratory work, unless at the expense of their own more proper field of investigation, I will here endeavour to assist the student by giving him a condensed abstract of so much of the elements of chemical mineralogy as may be sufficient for this purpose.

Every true mineral has a definite chemical composition, and a certain regular form, each of which is both produced and modified according to general laws.

1. Laws of Composition.

A. *Simple Bodies.*—All substances are either simple or compound. If simple, they are some of the sixty enumerated in the following table, in which the letters preceding the names are the symbols ordinarily used for them, the figures following some of them are their specific gravities, and the italic letters after a few, indicate their ordinary physical state—*g.* meaning gaseous, and *l.* liquid, the rest being all solid.

These simple or *elementary* substances are arranged in this table by my friend and colleague, Dr. W. K. Sullivan, in an order adapted merely to shew the relations which are stated in it. Other orders of arrangement may be used for other purposes. Carbon, for instance, might be classed with Silicon and Boron, since they are in some respects closely allied, all three having been found in three states, namely, amorphous, crystallised in the regular, and crystallised in the hexagonal systems, and diamonds of Silicon and Boron are known, as well as those of Carbon.

B. *Compound Substances.*—All other substances are *combinations* of two or more of the simple substances contained in Table I. A combination is not a mere *mingling* of two substances producing a mixture intermediate between the two, but a *union* producing a *third substance* different from either.

These combinations do not take place indifferently, but according to certain strict rules or laws, of which the two following are the most important.

1. *Elective affinity.*—One substance will combine with another in preference to a third, or, in some cases, in preference to any other. This preference is denoted by the term "elective affinity."

TABLE I.—List of Elementary Bodies.

Metalloids.

Organogens (forming animal and vegetable bodies.)

O. Oxygen. *g.*	
H. Hydrogen. *g.*	
N. Nitrogen. *g.*	
C. Carbon.	3.5

Amphigens (whose compounds with other elements, possess a marked dualism, i. e., some strongly acid, some strongly basic. Oxygen is amphigenous also).

S. Sulphur.	2.0
Se. Selenium.	4.3
Te Tellurium.	6.2

Halogens (forming salt-like bodies with metals, as common salt).

F. Fluorine. *g.* ?	
Cl. Chlorine. *g.*	1.3
Br. Bromine. *l.*	2.9
I. Iodine.	4.9

Phosphoroids.

P. Phosphorous.	1.7
As. Arsenic.	5.9

Hyalogens (glass-formers, because the salts in which their oxides, Silica and Boracic acid, act as acids, fuse into glass at a high temperature).

B. Boron.	
Si. Silicon.[1]	

Metals.

1. *Which decompose water at ordinary temperatures.*

(*a*) *Whose protoxides are alkalies.*

K. Potassium.	0.86
Na. Sodium.	0.97
Li. Lithium.	0.59

(*b*) *Whose protoxides are alkaline earths.*

Ba. Barium.	4.0?
Sr. Strontium.	2.54
Ca. Calcium.	1.57
Mg. Magnesium.	1.74

2. *Metals whose oxides are earths.*

Al. Aluminium.	2.67
G. Glucinum.	2.10
Zr. Zirconium.	
Y. Yttrium.	
Tb. Terbium.	
E. Erbium.	
Th. Thorinum.	

3. *Metals whose oxides resemble earths.*

Ce. Cerium.	
La. Lanthanum.	
D. Didymium.	

4. *Metals whose protoxides are isomorphous with magnesia.*

Mn. Manganese.	8.01
Fe. Iron	7.84
Co. Cobalt.	8.95
Ni. Nickel.	8.82
Zn. Zinc.	7.14
Cd. Cadmium.	8.60
Cu. Copper.	8.92
Pb. Lead.	11.44

5. *Metals isomorphous with phosphorus and arsenic.*

Sb. Antimony.	6.71
Bi. Bismuth.	9.80

6. *Metals not included in foregoing whose oxides are not reduced by heat alone.*

St.* Tin.	7.29
Ti.* Titanium.	5.33
Cr.* Chromium.	7.01
V.* Vanadium.	
W.* Tungsten.	17.60
Mo.* Molybdenum.	8.62
Os.† Osmium.	10.00
U. Uranium.	9.0
Ta. Tantalum.	
Nb. Niobium.	

7. *Noble metals, or those whose oxides are reduced by heat alone, and which are usually found native, and rarely or never combined with oxygen.*

Hg. Mercury.	13.59
Ag. Silver.	10.53
Au. Gold.	19.34
Pt. Platinum.	21.50
Pd.† Palladium.	11.80
Ir.† Iridium.	21.80
R.† Rhodium.	11.20
Ru.† Ruthenium.	8.60

[1] Silicon is now shewn distinctly not to be a metal, but to be nearly allied to carbon in some of its properties. It will combine with the metals like carbon, especially with aluminium, forming *cast aluminium*, as carbon and iron form *cast iron.—Comptes Rendus*, 1854, p. 321.

* Those marked thus have isomorphic relations with the metals that are isomorphous with magnesia.

† These are found associated in native platinum.

By means of this affinity some combinations may be *decomposed*. If, for instance, there be a compound substance, X, composed of two simple substances *a* and *b*, of which *a* has a greater affinity for another simple substance *c* than it has for *b*; then, if we bring this third substance into connection with X, under the requisite conditions, *a* will unite with *c* to form another compound substance Y, while the simple substance *b* will be left free.

2. *Definite proportion.*—Simple substances not only have an elective affinity for each other, but their combinations take place only in certain definite proportions with each other. In that combination, for instance, of the gases oxygen and hydrogen, which produces water, eight parts by weight of oxygen combine with one part by weight of hydrogen, any surplus of either that might be present remaining unused.

Equivalents.—The numbers denoting these proportions are called the equivalent numbers, 8 being the equivalent of oxygen and 1 that of hydrogen.*

The equivalents of the compound substances are the sums of those of their elements; thus the equivalent of water is $(8 + 1 =)$ 9.

B 1. *Primary compounds.*—The union of two simple substances is termed a binary (twofold) compound, or may be called a primary compound, as denoting the *first* possible combination.

The two substances entering into combination are always considered as in opposite electrical conditions, one being electro-negative and the other electro-positive.

The generic name of a primary (or binary) compound is formed by adding the affix *ide* (or *uret*†) to the first syllable of the name of its electro-negative element, placing after it the name of the other element with the word *of* between. Thus—

The Compounds of	Are termed	Example.	Symbol.
Oxygen.	Oxides.	Oxide of zinc.	Zn O.
Carbon.	Carbides, or carburets.	Carbide of iron. Carburet of hydrogen.	Fe_4 C. H_4 C_4.
Sulphur.	Sulphides, or sulphurets.	Sulphide, or sulphuret of potassium.	K S.
Fluorine.	Fluorides.	Fluoride of calcium.	Ca F.
Chlorine.	Chlorides.	Chloride of sodium.	Na Cl.

* Any other numbers having the ratio 8 : 1 would do equally well; accordingly, it is often found more convenient to make the equivalent of oxygen 100, when that of hydrogen would become 12.5, for $12.5 \times 8 = 100$, and so of the rest.

† Chemists are now gradually leaving off the use of "uret" as a termination. The unions of two metals are called "alloys;" those, however, with mercury are called "amalgams."

When it is said that simple bodies only combine in certain definite proportions, it must not be inferred that each has only one proportion of combination; on the contrary, they may combine in any simple multiple of that proportion, as twice, thrice, four times, etc., or even in one-half or two-thirds of the normal proportion or equivalent. The names of such compounds are formed by placing a prefix to the generic name expressive of the number of equivalents of the electro-negative element in it.

The following Table affords examples of these names :—

TABLE II.

When the proportion is as	The prefix is	Examples.	Symbols.
1 : 2	Di (half), or Sub (under).	Dioxide of copper. Diniodide of copper. Subchloride of mercury.	$Cu_2 O$. $Cu_2 I$. $Hg_2 Cl$.
1 : 1	Proto (first).	Protoxide of iron.	$Fe O$.
3 : 2	Sesqui (one and a half).	Sesquioxide of iron.	$Fe_2 O_3$.
2 : 1	Deuto, or bi (twice).	Deutoxide of lead. Binoxide of manganese. Bichloride of platinum.	$Pb O_2$. $Mn O_2$. $Pt Cl_2$.
3 : 1	Tri, or ter (thrice).	Tritoxide of osmium. Teroxide of gold. Terchloride of arsenic.	$Os O_3$. $Au O_3$. $As Cl_3$.
4 : 1	Tessara, or quadri (four).	Tessaroxide of osmium. Quadri-sulphide of osmium.	$Os O_4$. $Os S_4$.
5 : 1	Penta (five).	Pentachloride of phosphorus.	$P Cl_5$.
When in a series of compounds one has the largest number of equivalents of the electro-negative element, whatever that number may be.	Per (complete).	Peroxide of iron. Peroxide of hydrogen. Peroxide of osmium. Perchloride of antimony.	$Fe_2 O_3$ $H O_2$. $Os O_4$. $Sb Cl_5$.

Acids and Bases.—These primary (or binary) compounds have different properties, from which they are called *acid*, *basic*, or *indifferent ;* thus there are ox-acids, sulph-acids, chlor-acids, etc., oxy-bases, sulpho-bases, chloro-bases, etc., and indifferent oxides, etc. For our purposes, however, we may dismiss from consideration all acids except those in which oxygen forms the electro-negative element ; and we may then state that all acids are either deutoxides or tritoxides, or have a still higher proportion of oxygen in combination ; that the indifferent bodies are either sesquioxides, or, at most, deutoxides ; while the bases are either protoxides or sesquioxides.

It is, however, the bases, and in part the indifferent bodies, which are alone termed oxides. The acid compounds have special names, formed by appending a syllable to the termination, or modifying the final syllable of the electro-positive element, and adding the word "acid." Thus the acid oxide of carbon (CO_2) is termed carbonic acid, and one of the acid oxides of sulphur (SO_3) sulphuric acid.

When a simple body forms with oxygen two oxides having acid properties, the name of that which contains most oxygen ends in *ic*, and that having least in *ous*. Examples—(SO_2), sulphurous acid ; (SO_3), sulphuric acid.

At the time of the framing of this nomenclature no bodies were known forming more than two acid oxides. Others, however, have since been discovered, and they are described by the prefix of *hypo* "under," placed before the words ending in *ic* or *ous*, according to the relation which it is desired to express. If an acid be discovered containing more oxygen than the one previously known, and ending in *ic*, it takes the prefix *per*. Examples—($Cl\ O$), hypochlorous acid ; ($Cl\ O_3$), chlorous acid ; ($Cl\ O_4$), hypochloric acid ; ($Cl\ O_5$), chloric acid ; ($Cl\ O_7$), perchloric acid.

Many acids have a sharp taste (whence the term "acid" originated), and have the property of reddening many blue vegetable colouring matters, such as that of the violet, red (purple) cabbage, litmus, etc. Such acids are, of course, soluble ; but there are many which are insoluble, and exhibit no action upon colouring matters, and have no sharp taste. Hence chemists no longer consider those properties as the essential qualities of an acid, and have accordingly agreed to consider that body as an acid which appears at the positive pole when a salt is decomposed by the action of a voltaic battery ; or, in other words, *an acid* is the *electro-negative* constituent of a salt.

Some bases which are soluble have the property of changing the blue colouring matter of red cabbage to green, and the bright yellow of turmeric to brown, and of restoring the blue of litmus reddened by an acid. But as many substances are considered as bases which do not

possess this property, chemists have agreed to consider as *a base* the *electro-positive* constituent of a salt, or that which appears at the negative pole in the process of electrolysis. Some bodies possess the acid or basic properties so weakly, that they are capable of acting in either capacity, according to circumstances, that is, they act as bases with strong acids, and as acids with strong bases. Such bodies may be termed *indifferent.**

B 2. *Secondary compounds or salts.*—Acids and bases form combinations with each other which are termed salts. In these combinations, the electro-negative element is most usually the same in the acid and the base, an oxygen acid uniting with an oxygen base, a chlorine acid with a chlorine base, and so on. There are, indeed, some salts, both natural and artificial, composed of unions of different elements, especially oxygen and chlorine, but for our purpose we may dismiss from consideration, as before, all acids and bases except those which are oxides.

Salts, then, or the unions of acid and basic oxides may be termed ternary compounds, as being combinations of three substances, or secondary compounds, as being the second possible combinations.

The primary compound substances, acids and bases, combine with each other in the same way that simple substances do; that is, through elective affinity for each other, and in definite proportions with each other.

The unions of acids and bases, therefore, may be expressed in the same way, and by using similar prefixes, affixes, etc., to those which denote the union of the simple substances.

The name of an oxygen salt is formed by modifying the termination of the acid, changing "ous" into *ite*, and "ic" into *ate*. Example—Sulphurous acid and soda form sulphite of soda, sulphuric acid and potash form sulphate of potash.

"If the acid have the prefix *hypo* or *per*, it is retained in the name of the salt—example, hypochlorous acid and soda form hypochlorite of soda, perchloric acid and potash form perchlorate of potash.

"Again, the very same acid and base may unite in different proportions, and produce another set of salts. In such cases the one considered to be the neutral salt receives a name formed in the manner just described, while those which contain more acid or base than it are distinguished by prefixes, in the same manner as in the combinations of the simple substances." (See Table II.)

Summary.—The conclusions we have now arrived at may be summed up as follows:—

* Alumina is an example of such a substance, as it acts as the acid in spinel, and is supposed to replace silica in some hornblendes, and as a base in alum and in most aluminous silicates.

In the first place, all substances the names of which end in "ide" (or "uret"), and the acids ending in "ic," or "ous," are composed of two elementary constituents only, their varieties resulting from the different proportions in which those constituents are combined.

Secondly, all substances of which the names end in "ate" (such as sulphate, carbonate, silicate), are salts, however hard, insoluble, or tasteless they may be, the essential character of a salt being that it is the union of an acid with a base.

We also learn that while there are some substances, each of which may form many varieties of acid, according to the various multiple proportions in which oxygen may combine with it, there can be only two basic varieties of any one substance, that which is called its protoxide and that which is called its sesquioxide. There can then be two, and only two, sets of salts formed by any one substance and any one acid, the protoxide and the sesquioxide salts, but that each of those sets of salts may also have several varieties, depending on the different multiple proportions in which the acid may unite with the base.

Salt-radicle Theory.—If, however, the above restriction to the use of the word "salt" be established, it follows that the chemical meaning of the term "salt," is not only different from its ordinary meaning, but directly opposed to it; because common salt (Na Cl.) is not the union of an acid and a base, but that of two simple substances, sodium and chlorine, and therefore is a primary compound instead of a secondary compound or salt.

It appears, however, that this anomaly may be rectified or evaded by viewing the combination of an acid with a base as merely a binary compound of a metal with a salt-radicle, and not as a union with two distinct molecular groups. Sulphate of potash, for instance, would be considered not so much the combination of tritoxide of sulphur with oxide of potassium, but as a combination of potassium with quadroxide of sulphur. In this way common salt, chloride of sodium, becomes strictly analogous to all other salts, as in the following expressions:—

	Acid Theory.	Salt-radicle Theory.
Sulphate of Potash . . .	$KO + SO_3$	$K + SO_4$.
Nitrate of Potash . . .	$KO + NO_5$	$K + NO_6$.
Chloride of Sodium . . .		$Na + Cl.$

In the ordinary use of terms descriptive of salts, the bases of which have no special names (like Lime for the oxide of Calcium), the words "oxide of" are often omitted, thus sulphate of iron means sulphate *of oxide* of iron, since in the commonly used nomenclature the simple substance iron is only supposed to combine with the simple substance sulphur (producing sulphide or sulphuret of iron), and not with its

oxygen acid (sulphuric acid), which is ordinarily supposed to require an oxygen base.

Relation of the oxygen in the base to that in the acid—In order to completely understand the terms descriptive of the formation of salts, it is necessary not merely to look upon them as unions of a base with an acid, but also to notice the nature of the combination as regards the proportions of oxygen in each.

" If we take sulphuric acid (SO_3) and potash (KO), for instance, it is found by experiment that they combine to form a neutral salt, sulphate of potash, in such proportionate quantities that the ratio of oxygen in acid : that in base : : 3 : 1. Chemists have then agreed to consider, by analogy, all the sulphates of the oxides of the metals as neutral salts which have the same ratio of—

Oxygen in base : oxygen in acid : : 1 : 3.

All neutral salts, therefore, require one additional equivalent of acid to every additional equivalent of oxygen in the base. If we represent the metals by the common symbol R, then the following formulæ would represent the composition of the neutral sulphates ; for—

		O in base.		O in acid.	Ratio of No. of equivalents of base to No. of acid.		
Protoxides	$RO + SO_3$	1	:	3	1	:	1
Sesquioxides	$R_2O_3 + 3SO_3$	1	:	3	1	:	3
Deutoxides	$RO_2 + 2SO_3$	1	:	3	1	:	2

" The ratio of the oxygen in the base to that in the acid varies of course for every acid, but is the same for all the salts which are considered neutral that are formed by the same acid with a series of bases ; thus :—

In carbonates it is as . . . . . 1 : 2
In chlorates . . . . . . 1 : 5
Etc. etc.

" *Formation of Silicates.*—The salts which silica is capable of forming with the bases are extremely numerous, and are seldom of so simple a composition as those for which the ordinary nomenclature was constructed ; hence when the chemical composition of minerals began to be studied, and chemical names given to them, a somewhat different system of nomenclature was unfortunately adopted. Thus, those silicates in which the proportion of acid to base, whether that base were protoxide or sesquioxide was as 1 : 1, were called silicates or *mono*silicates, where that relation was 2 : 1 *bi*silicates, where 3 : 1 *tri*silicates. Those

in which the proportion of acid was less than that of a monosilicate were called *sub*silicates.

"If silica be a teroxide ($Si\,O_3$), then it is clear that what was called a trisilicate of a sesquioxide should, in harmony with the nomenclature just given, be considered as the neutral silicate, and the *bi*silicates and *mono*silicates as basic salts. If, on the other hand, we adopt the preferable formula $Si\,O_2$, or consider silica a *deut*oxide, then the formerly basic silicate $3\,(R\,O) + 2\,(Si\,O_3)$ would become the monosilicate with the much more simple formula $RO + Si\,O_2$. The determination of whether silica be a deutoxide or teroxide was attended with considerable difficulties; but the balance of evidence now leans so strongly in favour of the former, that however the previously used symbol of $Si\,O_3$ may linger among mineralogists, chemists are universally discarding it as entirely out of harmony with all the recently discovered facts of the science. Adopting then the formula $Si\,O_2$ for silica, the following table will represent the general formulæ for many of the simple silicates hitherto examined, whether natural or artificial.

TABLE III.

Relation of Oxygen in the	Acid Base.	Name.	Formulæ of Silicates of Protoxides.	Formula of Silicates of Sesquioxides.
Acid in excess.	6 : 1	Trisilicate.	$RO, 3\,Si\,O_2$.	$R_2\,O_3, 9\,Si\,O_2$.
	4 : 1	Bisilicate.	$RO, 2\,Si\,O_2$.	$R_2\,O_3, 6\,Si\,O_2$.
	3 : 1	Sesquisilicate.	$2\,RO, 3\,Si\,O_2$.	$2\,R_2\,O_3, 9\,Si\,O_2$.
Neutral Silicate.	2 : 1	Monosilicate.	$RO, Si\,O_2$.	$R_2\,O_3, 3\,Si\,O_2$.
Basic Silicates.	1 : 1	Disilicate, or bibasic.	$2\,RO, Si\,O_2$.	$2\,R_2\,O_3, 3\,Si\,O_2$.
	1 : 1½ or 2 : 3	Tribasic silicate.	$3\,RO, Si\,O_2$.	$R_2\,O_3, Si\,O_2$.
	1 : 2 or 2 : 4	Quadribasic silicate.	$4\,RO, Si\,O_2$.	$4\,R_2\,O_3, 3\,Si\,O_2$.
	2 : 6 or 1 : 3	Sexbasic silicate.	$6\,RO, Si\,O_2$.	$2\,R_2\,O_3, Si\,O_2$.
	4 : 3	Two-thirds silicate.	$3\,RO, 2\,Si\,O_2$.	$R_2\,O_3, 2\,Si\,O_2$.

"Those silicates of the sesquioxide bases which are underlined, are found most frequently, indeed we might almost say exclusively, in the double silicates of alumina. Such silicates as two-thirds, three-fourths, etc., are perhaps not simple silicates, but compounds of other more simple ones. It may hereafter be found that the number of silicates which exist naturally in combination is much smaller than has been supposed."—W. K. S.

2. Laws of Form.

The definite geometrical form of a mineral is called its crystal. A crystal is not necessarily transparent, many are opaque; the definite form being its only essential attribute.

Axes of Crystals.—The forms of crystals are very numerous, but all those which occur naturally in minerals may be classed into six systems of crystallization, depending on the position of the "axes," or right lines about which their faces are symmetrically arranged.

It is obvious that the "axes" of any body are infinite, since we may suppose it to be concentrically enclosed in a sphere with an infinite number of diameters. The "symmetrical axes," however, are those only which join similar opposite points of a regular figure, as, for instance, the centres of opposite faces, the centres of opposite edges, or the opposite angles or corners of a solid.

A cube has six faces, twelve edges, and eight angles (or corners), therefore a cube will have thirteen symmetrical axes, namely, three joining the centres of the six opposite faces, six joining the centres of the twelve opposite edges, and four joining the eight opposite angles. (*See* fig. 1, *a*, *b*, and *c*.) In the majority of instances it will be sufficient to select those three symmetrical axes which express the ordinary dimensions of length, breadth, and thickness. It is, however, more convenient, in one case, to take four axes, since what we may call the breadth or thickness is equal in three directions.

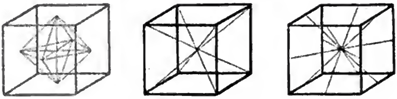
The six systems of Crystals.—These six systems of crystallization have been very variously named, and also differently numbered, in different works on mineralogy and chemistry. In drawing up the following list I have been guided chiefly by Regnault's Crystallography, Nicol's Elements of Mineralogy, and the Rev. W. Mitchell's Crystallography in Orr's Circle of the Sciences.

1. The first or regular, or cubical or octahedral, or tesseral or isometrical system, has three equal axes at right angles to each other. The typical form is either the cube with six equal square faces, or the

regular octahedron with eight faces formed of equilateral triangles. (See fig. 1, *a*.)

Fig. 1.

a *b* *c*



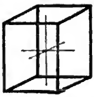
2. The second, or square prismatic, or pyramidal, or tetragonal, or monodimetrical, or two-and-one axial system, has three axes at right angles to each other, of which only two are equal to each other. Its typical form is either the right prism on a square base, or the right double four-faced pyramid, with eight faces formed of isosceles triangles. (See fig. 2.)

3. The third, or hexagonal, or rhombohedral, or monotrimetrical, or three-and-one axial system, has four axes, three of which are equal and cross each other at angles of 60° in the same plane, the fourth being not equal with them, and at right angles to them. Typical form a right prism on a hexagonal base (see fig. 3), or a right double six-sided pyramid, with twelve faces formed of isosceles triangles. The rhombohedral forms are hemihedral (see next page) modifications of the latter.

Fig 2

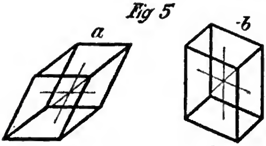
Fig 3

Fig 4



4. The fourth, or rhombic, or rhombic-prismatic, or orthotype, or prismatic, or one-and-one axial system, has three axes which are not equal, though all are at right angles to each other. (See fig. 4.) Typical form a right prism on a rhombic base, or right octahedron with a rhombic base, and eight faces formed of scalene triangles.

Fig 5

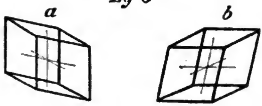


5. The fifth or oblique, or monoclinohedric, or hemiprismatic, or hemiorthotype, or clinorhombic, or hemihedric-rhombic, or two-and-one membered, system, has three unequal axes, two of which are oblique to each other, and the third at right angles to the other two. (See

fig. 5.) The typical form may be taken as the oblique prism on a rectangular or rhombic base, or the inclined (or oblique) double four-faced pyramid or octahedron on a rhombic base.

6. The sixth, or doubly oblique, or anorthic, or triclinohedric, or anorthotype, or tetarto-prismatic, or tetarto-rhombic, or one-and-one membered, system, has three axes all oblique to each other, which may have any possible relation as to length. (See fig. 6.) The typical form is the doubly oblique prism, or the doubly oblique octahedron or pyramid.*

Fig 6



Holohedral and hemihedral crystals.—The first and most obvious modification of these crystalline forms, is that consequent upon halving them. We may conceive in each of the preceding systems a form produced by the growth of half, instead of the whole crystal, the one called the hemihedral (from the Greek "hemi," a half, and "hedra," a seat or basis), and the other the holohedral (from the Greek "holos," the whole). There will be sometimes, then, two distinct series of forms under each system. The most remarkable, perhaps, of these is the production of the six-sided rhombohedral forms of the third system from the twelve-sided pyramids of that system.

Derivative forms.—Other modifications may be derived from the typical forms in the following way:—

In fig. 1, *b*, the eight corners of the cube are joined by four axes or lines passing through the centre of the cube. If now we suppose each of these eight corners to be truncated (or cut off) by a plane, at right angles to its axis, we shall get eight new faces, and if equal portions be cut away until these new faces meet or touch each other, it will be obvious that the result will be the octahedron, or figure bounded by eight sides, which will be equilateral triangles.

In fig. 1, *c*, the twelve edges of the cube have their centres joined by six axes, and if in like manner each of these edges be truncated by planes at right angles to the axis, we shall get twelve new faces, and if equal portions be cut off till these new faces meet or touch each other, we shall have a regular twelve-sided figure, or dodecahedron formed, each of its faces being a rhomb.

Or, *vice versa*, if we have the octahedron or dodecahedron, we may

* Nauman and other chemists now propose to adopt seven systems of crystallization; three upright forms with three axes, three inclined forms with three axes, and one hexagonal with four axes. The crystallization of some artificially formed substances justifies this proposal, but the six systems given above include all naturally formed substances. (*Information received from Dr. Sullivan.*)

convert it into a cube by supposing regular increments added to each face, so as to build up the corners or edges of the cube.

Then, again, we may suppose the above-mentioned increments or decrements not complete, the cube having its corners or edges cut off regularly and equally, but not to a sufficient extent for the new faces to touch each other. We might, for instance, have a cube with portions of its original six faces remaining, and eight new smaller faces where the corners were cut off, making a regular figure with fourteen faces, or if the twelve edges were so cut, we might have a regular figure with eighteen faces.

Still further modifications may be formed by the superposition of one of these modifications on the faces of another, as we may imagine, for instance, the pyramidal end of an octahedron growing out of the face of a cube.

What is true of the first, is equally true of all the other systems.

The student may now understand how the almost infinite diversity of natural forms may be reduced to a comparatively simple system, by seeing how a few regular modifications of simple and regular forms will result in a wonderful complexity of geometrical figures.

Macles.—There are, moreover, forms produced by twin crystals, the principal axes of which cross each other, either at right angles or at some other definite angle, thus producing crystals in the form of a cross, or half a cross, either rectangular or oblique.

Cleavage.—All crystals have a natural cleavage or tendency to split and produce perfectly smooth faces parallel either to the faces of the original typical form or to some of the faces thus produced by regular and symmetrical modifications of that form. It is by taking advantage of this natural cleavage that hard gems are cut by jewellers.

Isomorphism, Dimorphism, and Allotropism.—It has been said that all minerals, properly so called, possess a definite chemical composition, *i.e.*, are made up of precisely the same ingredients in exactly the same proportion ; and also a definite form, that is, are either one of the primary or typical forms mentioned above, or a modification of one of those forms.

We have now to modify this statement, since it has been found that there are certain groups of substances which can be substituted for each other, under certain conditions, without producing any noticeable change of form in the crystal of the mineral, and also that some substances, retaining the same chemical composition, do, under certain conditions, assume more than one definite form.

Different specimens then may contain different proportions of the same ingredients or even different ingredients, and yet retain the same

form, and remain the same mineral, provided the variation occurs only among these groups of substances.

Substances possessing this power of replacing each other are said to be isomorphous, or "retaining the same form" (from two Greek words, "isos," equal, and "morphe," form). Among the substances mentioned at p. 30 in Table V., for instance, potash, soda, lime, magnesia, protoxide of iron, and protoxide of manganese (all being simple oxides), are isomorphous. Alumina and peroxide of iron, again (both sesquioxides), are isomorphous. One consequence of this law is, that we find considerable differences between the different analyses of the same mineral, according as each specimen analysed, contains more or less of different isomorphous substances. It is hence necessary always to reduce the analyses of minerals to a theoretical or normal formula, which groups the isomorphous bases together, and points out the relations of the group to the acids present in the mineral. Such a group of bases is commonly denoted by the letter $\bar{R}$ in chemical formulæ.*

* "One of the best examples of isomorphism is presented by the various alums, of which there are no less than twelve, all of which crystalise in regular octahedrons, and may be represented by the following formula :—

$$RO, SO_3 + R_2O_3,\ 3\ SO_3 + 24\ HO.$$

Now, in this formula, RO, the protoxide base may be any one of the three substances KO (potash); Na O (soda), NH_4O (oxide of ammonium); and R_2O_3, the sesquioxide base may be any one of the four substances AL_2O_3 (alumina), F_2O_3 (sesquioxide of iron), Cr_2O_3 (sesquioxide of chromium), or Mn_2O_3 (sesquioxide of manganese). There are, therefore, $3 \times 4 = 12$ possible combinations.

Perfectly isomorphous bodies or *isotomes* are those which have the same crystalline form, and similar formulæ, and equal atomic volumes. The conditions for perfect isomorphism can only be fulfilled in crystals belonging to the regular system.

Those in which the last conditions are only partially, or not at all fulfilled, are said to be *homoiomorphous.* The replacement of an equivalent of one body by a multiple of the equivalent of another, is termed *polymeric isomorphism.* Thus, for example, according to Scheerer, 3 Ho (3 equivalents of water) can replace Mg O (magnesia), without changing the form.

Heteronomic isomorphism is that kind of homoiomorphism in which the condition of equal atomic volumes is fulfilled by dividing the unequal atomic volumes of two homoiomorphous bodies by the number of atoms in each compound. Dana has applied this property to connect together different formulæ. The analysis of some minerals led to the following general formulæ; and from them were calculated the annexed atomic volumes :—

$$\text{No. 1. } (RO)_3\,(Si\,O_3)_2 + 3\,(R_2\,O_3,\ Si\,O_3) = 1808.$$
$$\text{No. 2. } (RO)_3\,(Si\,O_3)_2 + 6\,(R_2\,O_3,\ Si\,O_3) = 3013.$$
$$\text{No. 3. } (RO)\,(Si\,O_3) + 4\,(R_2\,O_3,\ Si\,O_3) = 1850.$$

Now No. 1 contains 41 atoms and $1808 \div 41 = 44$.
And No. 1 ,, 68 ,, and $3013 \div 68 = 44$.
And No. 3 ,, 42 ,, and $1850 \div 42 = 44$.

The conditions of equal atomic volume were thus fulfilled.

Homoiomorphism has a very extended meaning, according to some persons, and is not, according to them, like true isomorphism, confined to forms of the same system alone, but may exist between forms belonging to two different systems. Thus, for example, orthoclase or potash feldspar is homoiomorphous with albite or soda feldspar, though the former belongs to the fifth and the latter to the sixth system."—(W. K. S.)

Dimorphism (from the Greek "dis" twice),* is the property which some substances have of crystallizing in two different forms belonging to two different systems of crystallization. These different crystals of the same substance vary not only in external form, but often also in density, hardness, etc.

They thus form different minerals, and go by different names, although they have essentially the same chemical composition.†

This assumption of a different form in the same substance often seems to depend on the different circumstances of temperature, etc., under which the crystals have been produced. "It is often remarked that crystals which have been formed at high temperatures, and which were perfectly transparent at the moment of their production, become opaque and pulverulent after a short time. Disaggregation ensues, because the molecules have a tendency to arrange themselves differently, in accordance with the forces which prevail at less elevated temperatures. It is often possible, when this alteration has occurred, to distinguish, with the aid of a magnifier, that the mass is formed of small rudimentary crystals possessing the form which the substance affects at ordinary temperatures."—*Regnault.*

A mineral, then, when composed of a substance possessing the property of dimorphism, might have an external crystalline form belonging to one system, while internally it is made up of crystalline particles belonging to another system.

Carbonate of lime crystallized from cool solutions takes the form of Calcite, but if their temperature exceed 150° it will become Arragonite. On the other hand, crystals of Arragonite heated by a spirit lamp, decrepitate and fall into powder, which consists of grains having the form of Calcite.

"Iodide of mercury, when freshly sublimed, is of a lemon yellow colour, but it gradually becomes scarlet as it cools, or suddenly if vibrated or pressed, or if the surface of a mass of crystals be scratched with a pin. A similar change of colour is observable in many cases where no dimorphism has been traced, because the substances have not crystallized in both states. Sulphide of mercury, for example, obtained by precipitating a salt of mercury with sulphide of hydrogen, is black, but when sublimed it constitutes cinnabar, which in powder forms the pigment vermillion. The change in colour is often accompanied by changes in other properties, and such changes also occur without any change of colour.

* The student will recollect that the syllable "di" may either mean "twice" or "half," according as it is derived from Greek or Latin.

† Some bodies are even capable of assuming three incompatible forms, and are therefore said to be *trimorphous.* Of these, sulphate of nickel is an example.—(W. K. S.)

Allotropism.—"This modification in the properties of a body, not resulting from chemical combination, has been called by Berzelius allotropy (from the Greek "allotropos," that which can be turned from one thing into another). Dimorphism is merely a particular case of allotropism, of the influence of which many other examples might be given did space permit.

"The glassy structure of bodies is connected with these phenomena. Most of the simple silicates of lime, iron, etc. (except perhaps the very basic silicates of lead), even when formed into perfect glass, do not retain that form, a crystalline structure being developed in them. But a mixture of such silicates forms true glassy masses, which remain permanently in the glassy state. Even in these, however, if kept in a soft state for a long time at a high temperature, a species of crystallization takes place, which is termed devitrification. This was at one time supposed to be the result of a separate crystallization of the simple silicates, but is probably only depending on the allotropism of the mixture.

"The amorphous condition of bodies would, in like manner, appear to be in some instances connected with allotropism. Many substances which are classed as amorphous exhibit a tendency to assume globular structures, which may perhaps be considered a third form, in addition to the glassy and crystalline states. Thus, for instance, carnelian, when polished and plunged into liquid hydrofluoric acid, is acted upon, and its surface in a short time exhibits the concentric layers so characteristic of agates.

"A peculiar kind of allotropism is observed among several metallic peroxides, as also several salts, silicates, etc., that, after being heated to a certain point, they cease to be soluble in acids, and this independently of the fact of those that are hydrates losing their water.

"This seems to be connected with the fact that Silica, for instance, is soluble in water in one allotropic state, and insoluble in another. It has quite recently been discovered that even alumina and sesquioxide of iron can be got in such a state as to be soluble in pure water or in weak acids, while at the same time they are insoluble in strong acids.—(See *Journal of Chem. Soc.*, vol. vi. p. 217—Walter Crum's paper on alumina; Pean de St. Gilles on iron, Compt. Rendus, tom. xl. pp. 568 and 1243.)

"When we consider these facts, and reflect on the numbers of bodies that are susceptible of an allotropic condition, and recollect that heat is evolved as a body passes from one state to another, especially, if indeed it be not always, in passing from the less permanent to the more stable condition, and that a difference of specific heat exists between different allotropic conditions of bodies, we cannot help believing that

a light is dawning upon us that must inevitably modify our explanations of the chemical phenomena of geology."—W. K. S.

Metamorphism from "meta" signifying change and "morphe" form, and *pseudomorphism* from "pseudos" false, are most interesting and important divisions of this subject, but they will be considered in a future place. A particular kind of pseudomorphism, called *paramorphism*, will also be hereafter alluded to, and in connection with that, the *paragenesis* (from "para" "side by side with," and "genesis" generation) of minerals in rocks.

CHAPTER II.

ROCK-FORMING MINERALS.

Let us now select from Table I. the following fifteen simple substances, which are more especially necessary for the study of lithology, and arrange them in Table IV. with their symbols and equivalents.

TABLE IV.

	Symbol.	Simple Substances.	Equivalent Number.
1	O	Oxygen	8.00
2	H	Hydrogen	1.00
3	C	Carbon	6.00
4	S	Sulphur	16.00
5	Cl	Chlorine	35.51
6	Si	Silicon	14.22
7	K	Potassium	39.17
8	Na	Sodium	23.21
9	Li	Lithium	6.54
10	Ba	Barium	68.53
11	Ca	Calcium	20.16
12	Mg	Magnesium	12.67
13	Al	Aluminium	13.69
14	Mn	Manganese	27.61
15	Fe	Iron	28.08

Of these simple substances the first five combine variously with each other and with the other ten to produce various primary compounds.

In what follows it must be understood that the attention is confined solely to those substances which commonly occur in rocks, those which are truly rock-constituents. With this limitation *strictly borne in mind* we may say that No. 1 Oxygen combines with all the rest, one after

another, to produce the most common substances we know, all, namely, except the last, in the following Table V.

Nos. 2 and 3, Hydrogen and Carbon, uncombined with Oxygen, are found only in organic products, and in those mineral substances which are derived from organic products, and do not enter into combination with any of the rest to produce rock-forming minerals. Sulphur No. 4 in combination with iron (bisulphide of iron, iron pyrites), frequently occurs in rocks, but cannot be said to be one of their constituent minerals. Chlorine No. 5 is found in combination with one only of the succeeding substances to produce a rock-forming mineral, namely, with sodium, to produce chloride of sodium or rock-salt.

TABLE V.

Name of Primary Compound.	Number of Equivalents of Simple Substances.			Symbol of Compound.	Equivalent of Compound.
1. Water	1 of oxygen to		1 of hydrogen	HO	9.00
2. Carbonic acid .	2	„	1 of carbon	CO^2	22.00
3. Sulphuric acid .	3	„	1 of sulphur	SO^3	40.00
4. Silicic acid (or Silica) . .	2	„	1 of silicon	$Si O^2$	30.22
5. Alumina . . .	3	„	2 of aluminium	$Al^2 O^3$	51.38
6. Peroxide of iron	3	„	2 of iron	$Fe^2 O^3$	80.16
7. Potash . . .	1	„	1 of potassium	$K O$	47.17
8. Soda	1	„	1 of sodium	$Na O$	31.21
9. Lithia	1	„	1 of lithium	$Li O$	14.54
10. Baryta . . .	1	„	1 of barium	$Ba O$	76.53
11. Lime	1	„	1 of calcium	$Ca O$	28.16
12. Magnesia . . .	1	„	1 of magnesium	$Mg O$	20.67
13. Protoxide of manganese .	1	„	1 of manganese	$Mn O$	35.61
14. Protoxide of iron	1	„	1 of iron	$Fe O$	36.08
15. Rock salt (or Chloride of sodium) . .	1 of chlorine to		1 of sodium	$Cl Na$	58.72

By examination and comparison of the two Tables IV. and V., it will be seen that the first five substances of Table IV. are the active substances which can combine directly with others. The other ten do not enter into combination with each other until they have first been vivified, as it were, by a union with the most active substance Oxygen.

Even then the simple oxides do not combine with each other, but only with those substances as Silica, which have received at least a double dose of Oxygen (or are deutoxides), or more feebly and rarely with the sesquioxides, as Alumina.

Even among those first five, combinations with Oxygen are more frequent than those with the other four, and more firm in proportion to its quantity. Combinations with water (H O) for instance, are more frequent than those with hydrogen, those with carbonic acid ($C\,O_2$) more frequent than those with carbon, and the carbonates are decomposed by the action of sulphuric acid ($S\,O_3$) much more readily than the sulphates by carbonic acid.

In the preceding Table V. will be found a list of all those primary compounds (or compounds of two elementary substances), a knowledge of which is essential for lithological purposes, together with the number of the equivalents of the simple substances of which they are compounded, the symbols representing those equivalents, and the resulting equivalents of the compounds.

Every mineral which enters as an essential constituent into the composition of rocks is either one of the simple substances contained in Table IV., one of the primary compounds mentioned in Table V., or lastly, a *secondary compound* or salt made up of the union of two or more of those primary compounds, or a mixture of such salts. The following descriptions include all the most important species.

Minerals formed of Simple Substances.

Of the simple substances contained in Table IV., two only are ever found as minerals, namely, Carbon and Sulphur.

1. *Carbon* when crystallized in the first system forms the *diamond;* when in an allotropic state it crystallizes in the third system, it forms *graphite* or *plumbago.* It is, however, only when found in an amorphous state as a constituent of coal that we need notice it for the purposes of lithology.

2. *Sulphur* is found crystalline in minute octahedrons about volcanoes, but pure sulphur never occurs as one of the uncombined constituents of rocks. It belongs to the fourth system, its specific gravity being 1.9 to 2.1.

Minerals formed of Primary Compounds.

Of the compound substances mentioned in Table V., Silica and Rock-salt only occur in nature as rock-forming minerals.

3. *Quartz* is formed of pure silica ($Si\,O^2$). Its crystals belong to

the third system, their most usual form being a six-sided prism ending in six-sided pyramids. It also frequently occurs in an amorphous state as a hard, compact stone, commonly milk white. Its specific gravity is 2.65.

Rock crystal, Bristol, and Irish diamond, etc., are common names for crystallized quartz.

When coloured by slight admixtures of other substances, as iron, manganese, etc., quartz goes under various names, according to the variety and arrangement of colours, state of transparency, etc.

When purple, it is called *amethyst;* smoky quartz is *cairngorm;* blue quartz is *siderite;* green quartz, *prase;* when yellow it is sometimes called *Scotch* or *Bohemian topaz. Agate, jasper, carnelian, onyx, sardonyx, catseye, Lydian-stone, bloodstone, chert,* and *flint,* are other forms of quartz.

Opal is hydrated silica, *i. e.,* having water chemically combined with the silica, *Menilite* and *Cacholong* are varieties of it; and *chalcedony* is a mixture of quartz and opal.

Siliceous sinter is an opaline silica deposited on the margins of some hot springs, having been dissolved in the water.

4. *Rock-salt* ($Na\ Cl$) occurs in large masses in some localities, in beds or veins. It is either amorphous, or more or less completely crystalline; the primary form of the crystal being a cube, and therefore belonging to the first system. Its specific gravity is 2.1 to 2.2.

Corundum or crystalline* alumina, and *specular iron* or crystalline sesquioxide of iron, would come under this head, but cannot be called constituents of rocks.

Red hæmatite, however, or the amorphous condition of sesquioxide of iron ($Fe_2\ O_3$) seems itself in some places to occur as a rock.—(See *Mems. Geol. Survey, Iron Ores of Great Brit.: Mr. Smyth's Observations on the Hæmatite of Cumberland*).

Minerals composed of a Salt or a mixture of Salts.

We shall take these in the following order, namely—1*st,* the combinations with Carbonic acid; 2*d,* those with Sulphuric acid; and lastly, those with Silicic acid.

Carbonates.—Of the carbonates there are two only which are of importance for our purpose, namely, those of lime and magnesia, to which one of iron may be added.

5. *Carbonate of Lime, Calcspar* or *Calcite,* is a very abundant mineral. It is a mono-carbonate, or composed of one equivalent of lime

* When the crystal of Alumina ($Al^2\ O^3$) is red it forms the ruby, when blue, the sapphire, when in powder, it is called emery.

and one of carbonic acid ($Ca\,O, CO^2$); the bicarbonate of lime, which would be symbolised as $Ca\,O, 2\,CO^2$, not being definitely known.

Its chemical composition is—

	Percentage.	Equiv.	At.
Carbonic acid	43.87	22.00	1
Lime	56.13	28.16	1
	100.00	50.16	

Its primary crystal is a rhombohedron, belonging to the third system, but the modifications of this form are very numerous, particular forms of crystals being often peculiar to particular localities. Count Bournon published a work containing 700 forms of crystals of calcite, of which, however, not more than about 56 are essentially distinct from each other. It is sufficiently soft to be scratched with a knife, and it effervesces freely with any mineral acid, even when very dilute. Its specific gravity is about 2.7.

When carbonate of lime dissolves in water holding CO^2 (carbonic acid), a bicarbonate is supposed to be formed, but on the evaporation of the water the CO^2 also escapes, and the simple carbonate alone remains. If bicarbonate of lime be really produced, it seems to be incapable of assuming a solid form. Sir R. Kane (Elements of Chemistry, p. 695, 2d edit.) says the solution of carbonate of lime in water containing carbonic acid is not due to the formation of a bicarbonate of lime, but to a specific solvent power which a solution of carbonic acid in water has on many bodies, as silica, phosphate of lime, etc., which are insoluble in pure water. Bischof (vol. iii. p. 171) says that carbonate of lime dissolved in water containing carbonic acid gas is probably in the state of a sesquicarbonate, and the same with dissolved carbonate of magnesia.

6. *Arragonite* is the same substance in a different form, the crystals belonging to the fourth system, and having many secondary forms.

It is rather harder than calcite, and its specific gravity rather greater, being sometimes as much as 3. It not unfrequently contains a small proportion of strontia.

The importance of arragonite as a constituent of rocks is very slight compared with that of calcite.

7. *Magnesite,* or *Carbonate of Magnesia,* is composed of one equivalent of carbonic acid and one of magnesia ($= Mg\,O, CO^2$), its normal composition being—

	Percentage.	Equiv.	At.
Carbonic acid	52.38	22.00	1
Magnesia	47.62	20.10	1
	100.00	42.10	

This is by no means an abundant or important mineral, carbonate of magnesia usually occurring in combination with carbonate of lime to form the mineral called—

8. *Dolomite* (from M. Dolomieu), *Bitter Spar, Brown Spar, Pearl Spar*, or *Magnesian Limestone.*

The chemical composition of this mineral varies according to the proportions of the two carbonates which are mingled in it. Its normal composition may be stated as $Ca\ O, CO^2 + Mg\ O, CO^2$, giving the following percentage—

Carbonate of lime	54.3
Carbonate of magnesia	45.7
	100.0

But the proportions vary greatly, and often indefinitely.

Its hardness and specific gravity are not greatly different from those of calcite, and its primary crystal is also rhombohedric (third system); but dolomite may be often distinguished from calcite by its peculiar pearly lustre, and by the comparative difficulty and slowness with which it effervesces in acids.

9. *Chalybite* (from Chalybs, a Greek word for iron), *Spathic iron ore, iron spar, or sphæro-siderite*, is a monocarbonate of protoxide of iron or $Fe'O, CO_2$, having the following percentage:—

$Fe\ O$	61.4
$C\ O_2$	38.6
	100.0

It is harder than calcite, with a specific gravity of 3.83 or 3.87. It is isomorphous with calcite. Its crystals belong to the third system. It is mentioned here as forming a constituent of the rock known as clay ironstone, in which it is mingled with clay in an amorphous state.

SULPHATES.—The only sulphate which is of any importance as a constituent of rocks is—

10. *Gypsum* (gypsos is the Greek word for this substance), or *Sulphate of Lime.*—The chemical composition of this mineral is one equivalent of lime, one of sulphuric acid, and two of water, being a bihydrated sulphate of lime. Its normal formula is $Ca\ O, SO^3 + 2\ HO$, giving the following percentage—

Lime	32.56
Sulphuric acid	46.51
Water	20.93
	100.00

Its crystalline system is the fifth or oblique prismatic. It also frequently occurs fibrous, granular, or compact. It is softer than calcspar, and its specific gravity is about 2.3.*

Compact white gypsum is called alabaster ; the transparent crystals are called selenite.

11. *Anhydrite* (from the Greek "a" or "an" without, and "hydra" water), is sulphate of lime without water, its formula being Ca O, SO^3, which gives—

Lime	41.18
Sulphuric acid	58.82
	100.00

It is harder and heavier than true gypsum. Its crystals are called *Muriacite.*

The combinations of lime and magnesia with gaseous carbonic acid may take place at the ordinary temperatures of the air, either directly from the atmosphere or through the medium of water, and that of lime with liquid sulphuric acid at any ordinary temperature.

SILICATES.—In order to induce the solid silicic acid, or Silica, however, to enter into combination with any of the bases, it is, in the majority of cases, necessary that the two be mingled together in a fine state of division, and be subjected to a very high temperature.

For the production of the artificial silicates, glass and porcelain, the heat of a furnace is necessary. It is useful to remember this fact when examining the great group of the natural silicates.

The silicates of potash and soda which are the bases of artificial glass, do not occur alone as natural minerals, though they enter into the composition of many.

Silicate of lime, however, occurs both as a detached simple mineral called *Wollastonite* (after Dr. Wollaston), or *Tabular Spar*, and as a constituent of other minerals.

The silicates of magnesia form minerals, which are of more importance for our purpose, of which the four following may be described—

12. *Chrysolite* (from "chrysos," gold, and "lithos," stone), *and Olivine*, consists of two equivalents of magnesia to one of silica, having the normal formula 2 Mg O, Si O^2, which gives the percentage—

Magnesia	56.34
Silica	43.66
	100.00

* The gypseous alabaster must not be confounded with the true or Oriental alabaster, which is a species of stalactitic carbonate of lime.—W. K. S.

The crystalline system is the fourth or right prismatic. The specific gravity about 3.4, harder than felspar, transparent, generally of a yellowish-green colour. It is infusible before the blow-pipe. Some of the magnesia is commonly replaced by iron, sometimes as much as 15 per cent.

13. *Serpentine* (noble serpentine) has three equivalents of magnesia to two of silica and two of water, having the normal formula 3 Mg O, 2 Si O^2 + 2 HO, or 2 (Mg O Si O^2) + (Mg O, 2 HO), giving the proportions—

Magnesia	42.86
Silica	44.28
Water	12.86
	100.00

Specific gravity 2.55, hard as calcspar, translucent, generally of a green colour and waxy lustre. Fuses at the edges before the blow-pipe to a white enamel.

Variegated Asbestos has the same composition.

Schillerspar and *Picrosmine* have nearly the same composition as Serpentine.

14. *Talc* is formed of five equivalents of silica with four of magnesia. Its normal formula may be stated as 2 (Mg O Si O^2) + (2 Mg O, 3 Si O^2), giving the following percentage—

Magnesia	34.04
Silica	65.96
	100.00

It occurs in rhombic and six-sided tabular crystals belonging to the third system; specific gravity about 2.7, softer than gypsum, translucent, pearly lustre, unctuous touch. Splits into laminæ before blow-pipe, and hardens without fusing.

15. *Steatite* (from "stear," fat), or *Soapstone*, has four equivalents of silica to three of magnesia, or Mg O, Si O^2 + 2 Mg O, 3 Si O^2, giving—

Magnesia	32.61
Silica	67.39
	100.00

Specific gravity 2.6, soft, unctuous, slightly translucent. Before blow-pipe fuses at edges to white enamel.

The following silicates of magnesia and lime are of still higher importance.

16. *Augite*, or *Pyroxene* (from "pyr," fire and "xenos," a guest), is most probably a monosilicate of magnesia and lime—that is, it contains two equivalents of silica to one of magnesia and one of lime, having the normal formula Ca O, Si O^2 + Mg O, Si O^2, which would give the percentage—

Magnesia	18.18*
Lime	25.46
Silica	56.36
	100.00

Its crystalline system is the fifth or oblique prismatic. Specific gravity about 3.4, hardness rather less than feldspar. Fuses with various degrees of facility according to composition, the magnesia being often replaced to a large extent by protoxide of iron.

Diallage, or *Bronzite*, has a similar composition, but the bases are more numerous and variable, and there is generally present 1 to 4 per cent of alumina, and from ¼ to 4 per cent of water.

Hypersthene is also like *Augite* in its chemical composition, but has commonly less lime.

17. *Hornblende*, or *Amphibole* (from the Greek word "amphibolos," doubtful), is a compound of 6 equivalents of silica to 5 equivalents of base; having the formula 3 (Mo, Si O^2), + 2 Mo, 3 Si O^2, where the base Mo denotes a variable mixture of magnesia and lime, and the protoxides of iron and manganese.

Alumina is often present either as an aluminate of magnesia, or an aluminate of iron; not unfrequently fluoride of calcium also occurs. The composition varies much, within certain limits, as may be seen from the following three analyses given by Gmelin :—

Lime .	13.19	9.82	14.41
Magnesia .	18.84	12.85	15.44
Iron, protox.	7.77	19.19	9.05
Silica .	46.53	50.71	47.86
Alumina .	12.10	7.01	13.24
Fluoric acid	1.57	0.42	
	100.00	100.00	100.00

* Analyses by Wackenroder, Bonsdorf, and Rose, come sufficiently near to this normal formula to warrant us in stating it as a good theoretical idea of augite. In fact, both lime and magnesia are variously replaced by oxides of manganese and iron. Many augites also contain alumina, and may then be looked on as mixtures of (say) 5 atoms of true augite with one of some kind of garnet.

Crystalline system the fifth or oblique prismatic. Specific gravity about 3.2 Hardness less than feldspar. Colour dark green, almost black sometimes. Before blow-pipe readily swelling up, and fusing to a dark glass.

Tremolite has a similar composition; a specific gravity of 2.93, and fuses with difficulty to a colourless glass.

Actinolite, similar composition; specific gravity 3.03; coloured green by chromium and iron.

Anthophyllite, similar composition; specific gravity 3.2; fuses with great difficulty to a blackish-gray glass.

Ordinary Asbestos, Amianthus (Greek words signifying "indestructible" and "unpollutable"), *Wood-asbestos, Petrified Cork, Byssolite*, etc., consist of tremolite, actinolite, or common hornblende, in a very fine fibrous state.

"When one atom of lime is fused with one atom of magnesia and two atoms of silica, or one atom of lime with two atoms of magnesia and six of silica, and the mass very slowly cooled, it crystallizes in the form of augite. The first mixture yields a mass resembling ordinary augite; the latter a mass like augite from Finland. In the cavities of a slag from an iron furnace, fed with a hot air blast, Nöggerath found artificial crystals of augite."—*Gmelin*, vol. iii. p. 402.

"G. Rose (Pogg. 22, 321) considers that augite and hornblende belong to the same class, and for the following reasons:—the angles of either of these minerals may be reduced to those of the other; crystals are found in the form of augite with the cleavage of hornblende; when crystals of hornblende and augite have grown together, their axes are parallel; the specific gravity and composition of the two minerals are identical; if the fused mass is rapidly cooled, it assumes the appearance of augite, and if cooled slowly, it seems to crystallize in the form of hornblende. When, therefore, both are found together, the hornblende surrounds the crystals of augite, which are the first produced. From this cause hornblende is accompanied by quartz, feldspar, albite, and other minerals which are formed by the slow cooling of molten masses; augite, on the contrary, is found with olivine, which crystallizes by rapid cooling. For the same reason, slags, from being too quickly cooled, yield only crystals of augite. According to Mitscherlich and Berthier, also the fusing together of lime, magnesia, and silica, yields white crystals of augite, but none of hornblende; and even *tremolite*, fused by Mitscherlich and Berthier in a charcoal crucible, or *actinolite*, by G. Rose, in a platinum crucible in a potter's furnace, solidified to a mass consisting of distinct crystals of *augite*—(G. Rose). It is remarkable that hornblende is always richer in silica than augite."—*Gmelin*, H. B., vol. iii. p. 408.

Uralite.—"Scheerer has used the law of paramorphic pseudomorphism to explain the structure of this mineral, which, with the composition of hornblende, has the external form of augite, and very often a crystal of true augite within it, while the external layer exhibits the cleavage, and all other properties of hornblende."—W. K. S.

The silicates of alumina are a still more important and numerous class than those of magnesia, especially those which are combined with silicates of potash, soda, lime, magnesia, etc.

Collyrite and *Opaline Allophane* are hydrated silicates of alumina, in which there is one equivalent of silica to two of alumina.

18. *Andalusite* and *Chiastolite* (andalusite from "Andalusia"; chiastolite from the Greek letter "chi," which it resembles in form), are anhydrous silicates of alumina, andalusite having the normal formula $Al^2 O^3, Si O^2$, and the percentage of—

Alumina	62.38
Silica	37.62
	100.00

Crystals right rhombic prisms of the fourth system. Specific gravity, andalusite, about 3.1; chiastolite, about 3.0. Andalusite harder than quartz; chiastolite softer than feldspar. Infusible.

19. *Staurolite* (from "stauros," a cross, and "lithos," stone), has two equivalents of silica to three of alumina; one of the latter, however, being generally replaced by one of peroxide of iron. Its normal formula is $2\ Al^2 O^3, Fe^2 O^3 + 2\ Si O^2$, giving the percentage of—

Sesquioxide of iron	17.6
Alumina	51.4
Silica	31.0
	100.0

It belongs to the fourth, or right prismatic system of crystallization.

The crystals frequently intersect each other in the form of a cross, whence its name. Specific gravity 3.5 to 3.8; harder than quartz. Translucent; dark red, or brown. Fuses at the edges to a black slag.

Clay, when pure, is a hydrated bisilicate of alumina.

Bole is the same, with part of the alumina replaced by peroxide of iron.

We pass over several minerals which occur rarely or in unimportant quantities, and come to

20. *Chlorite* (from "chloros," green like a growing plant), which is a compound of four equivalents of silicate of magnesia with 1 of silicate

of alumina and 3 of water. Its normal formula is $4\ Mg\ O,\ Si\ O^2 + Al^2\ O^3,\ Si\ O^2 + 3\ HO$, giving—

Magnesia	25.47
Protoxide of iron	14.94
Alumina	21.81
Silica	26.32
Water	11.46
	100.00

Crystalline system the third or rhombohedral. Specific gravity about 2.8 ; soft, dark green, nearly infusible.

21. *Biotite, Uniaxal* or *Magnesia Mica*, has a similar composition for its principal varieties. The following gives the composition deduced from some analyses—

Potash	8.44
Magnesia	16.14
Protoxide of iron	13.46
Peroxide of iron	6.67
Alumina	13.10
Silica	42.19
	100.00

Crystalline system the third or rhombohedral. Specific gravity about 2.8 ; hardness between gypsum and calcspar. Dark green or brown, inclining to black ; translucent. Fuses pretty easily to a semi-opaque glass.

Orthite has a somewhat similar composition, but contains a very variable quantity of water.

22. *Vesuvian*, or *Idocrase*, is a silicate of lime, combined with a silicate of alumina, having the formula $3\ Ca\ O,\ 2\ Si\ O^2 + Al^2\ O^3,\ Si\ O^2$, some of the lime being replaced by magnesia and protoxide of iron, giving the following analysis—

Lime	32.26
Magnesia	2.43
Protoxide of iron	3.80
Alumina	19.93
Silica	40.58
	99.00

It belongs to the second, or square prismatic system. Specific gravity = 3.3 to 3.4 ; harder than feldspar. Transparent, yellowish-green, swells up and readily fuses before blow-pipe.

23. *Garnet* is similar in composition to Vesuvian, but is dimorphous with it, belonging to the first or regular system of crystallization. Both the lime and the alumina, however, in the formula for Vesuvian, may be replaced by magnesia, manganese, and iron, and the analyses vary accordingly. We have, therefore, *calcareous-alumina garnet*, which predominates in Cinnamon stone ; *magnesio-alumina garnet* in the black garnet of Arendal ; *manganesio-alumina garnet* in a North American variety, and one from Brodbo ; *ferruginous alumina garnet* in Oriental Almandine and other red varieties of precious garnet ; and *calcareous iron garnet* in the ordinary yellow, brown, and black garnets, and in *Melanite.*

Specific gravity varies from 3.4 to 4.3, rather harder than quartz, transparent, of various colours, fuses readily into a transparent glass.

24. *Epidote* has three equivalents of protoxide bases to two equivalents of alumina, having the formula 3 (Ca O, Mg O, Mn O, Fe O), 2 Si O^2 + 2 (Al^2 O^3, Si O^2).

The protoxide base is lime in *Zoisite* or calcareous epidote, replaced in large measure by iron in *Pistacite* or ferruginous epidote, and by protoxide of manganese in *manganesian* epidote. In the two latter, part of the alumina is also replaced by the peroxides of manganese and iron. Epidote has for its primary crystal a right rhomboidal prism, (fourth system). Its specific gravity is 3.0 to 3.5 ; harder than feldspar ; fusible before the blow-pipe.

25. *Prehnite* has two equivalents of a silicate of lime to one of a silicate of alumina and one of water, or 2 (Ca O, Si O^2) + Al^2 O^3, Si O^2 + HO, giving—

Lime	26.74
Alumina	24.55
Silica	44.41
Water	4.30
	100.00

It appears then that Prehnite is a hydrated Epidote.

Crystalline system the fourth or rhombic, specific gravity 2.92, harder than feldspar, translucent, of a light colour, fuses to a blistered glass.

Many varieties of uniaxal or magnesia mica appear to have a somewhat similar composition, the protoxide bases being Mg O, KO, Ca O, Fe O. It has not been yet satisfactorily shewn whether the water which mica contains, is an essential constituent ; the same remark applies to the fluoride of calcium which it also contains.

26. *Scapolite*, or *Wernerite*, is Ca O, Si O^2 + Al^2 O^3, Si O^2, that is, a silicate of alumina with a silicate of lime, giving the percentage—

Lime	19.80
Alumina	36.35
Silica	43.85
	100.00

Crystalline system the second or square prismatic. Specific gravity 2.7 ; softer than feldspar. Colourless and translucent. Fuses before blow-pipe.

Anorthite has a similar composition ; small portions of the lime being replaced by potash, soda, and magnesia.

Palagonite is an amorphous highly hydrated Scapolite.

27. *Rhyacolite* (from "rhyax," a stream, *i.e.* of lava) consists of one equivalent of silicate of potash, soda, or lime, and one of a silicate of alumina ; or (KO, Na O, Ca O) $Si O^2 + Al^2 O^3$, 2 $Si O^2$, giving the percentage—

Potash	6.58
Soda	11.60
Lime	1.30
Alumina	28.66
Silica	51.86
	100.00

Its crystalline system is the fifth, or oblique prismatic. Specific gravity = 2.6. Before the blow-pipe, fuses rather more readily than feldspar (orthoclase).

28. *Pinite* has one equivalent of silicate of potash, or protoxide of iron, to one of bisilicate of alumina, and also contains water ; or (KO, Fe O) $Si O^2 + Al^2 O^3$, 2 $Si O^2$ + HO, giving—

Potash	12.42
Protoxide of iron	9.26
Alumina	27.04
Silica	48.92
Water	2.36
	100.00

Pinite then is hydrated Rhyacolite.

Its crystalline system is the third or hexagonal. Specific gravity 2.8. Softer than orthoclase ; slightly translucent. Becomes colourless before blowpipe, and fuses at edges to blistered glass.

29. *Labradorite* consists of one equivalent of silicate of soda, three of silicate of lime, and four of a silicate of alumina ; or Na O, Si O + 3 (Ca O, $Si O^2$) + 4 ($Al^2 O^3$, $Si O^2$), giving—

Soda	4.50
Lime	12.13
Alumina	29.68
Silica	53.69
	100.00

Crystalline system the sixth, or doubly oblique prismatic. Specific gravity about 2.7. Fuses rather more readily than orthoclase.

30. *Thomsonite*, or *Comptonite*, is exactly the same in composition, but containing a large proportion of water, so that its normal formula is given as $Na\,O, Si\,O^2, + 3\,(Ca\,O, Si^2\,O) + 4\,(Al^2\,O^3, Si\,O^2) + 8\,HO$, that is, 1 equivalent of silicate of soda, 3 of silicate of lime, 4 of silicate of alumina, and 8 of water.

Fourth or rhombic system. Specific gravity 2.3. Harder than fluor-spar. Transparent. Swells up before blow-pipe, becomes opaque, and fuses at edges to white enamel.

Thomsonite then is hydrated Labradorite.

31. *Leucite*, from "leucos" white, has one equivalent of silicate of potash, and one of silicate of alumina, or $KO, Si\,O^2 + Al^2\,O^3, 3\,Si\,O^2$, giving—

Potash	21.20
Alumina	23.09
Silica	55.71
	100.00

It belongs to the first or regular system; has a specific gravity about 2.4; a hardness rather less than orthoclase; is transparent, and infusible.

32. *Orthoclase* (from "orthos" straight, and "clao" to cleave, referring to its smooth cleavage), *Potash Feldspar*, or *Common Feldspar*, has one equivalent of trisilicate of potash and one of monosilicate of alumina, or $KO, 3\,Si\,O^2 + Al^2\,O^3, 3\,Si\,O^2$, giving—

Potash	16.59
Alumina	18.06
Silica	65.35
	100.00

Its crystalline system is the fifth or oblique prismatic. Specific gravity 2.5 to 2.6, increasing according as potash is replaced by soda or lime. Softer than quartz. Colourless, or slight flesh or yellow coloured. Fuses with great difficulty to a blistered turbid glass.

Adularia, or transparent Feldspar, and *Sanidine*, or Glassy Feldspar, are the same mineral as Orthoclase, but in the form of a glass more or less clear and transparent.

In the specimens of adularia from volcanic districts more than 4 per-cent of soda is sometimes found, while in that from St. Gothard, according to Abich, there is not more than 1 per cent.

The ornamental stones called Moon stone, and Amazon stone, are orthoclase.

33. *Albite* (from "albus" white), *Soda Feldspar*, has one equivalent of trisilicate of soda and one of monosilicate of alumina, or $Na\,O, 3\,Si\,O^2 + Al^2\,O^3, 3\,Si\,O^2$, giving—

Soda	11.62
Alumina	19.13
Silica	69.25
	100.00

It belongs to the sixth or doubly oblique system of crystallization. Its specific gravity is 2.6, and before the blow-pipe behaves like Orthoclase.

Pericline is an albite, in which part of the soda has been replaced by potash. It fuses more readily than albite.

34. *Stilbite*, or *Desmine*, has one equivalent of trisilicate of lime, one of monosilicate of alumina, and six of water, or $Ca\,O, 3\,Si\,O^2 + Al^2\,O^3, 3\,Si^2 + 6\,HO$.

Its crystal belongs to the fourth system. Its specific gravity is 2.2. It may be looked on as hydrated Albite, or Orthoclase.

36. *Oligoclase*, or *Soda Spodumene* (from "oligos" little, and "clao" to cleave, as not being so readily cleavable as orthoclase), is probably composed of three equivalents of monosilicate of soda, and four of monosilicate of alumina, which would be expressed by the formula, $3\,(Na\,O,\ Si\,O^2) + 4\,(Al^2\,O^3, 3\,Si\,O^2)$, in which O in a : O in b :: 30 : 15 : 2 : 1, or 3 (2 : 1) + 4 (6 : 3 = 2 : 1), but there is a little uncertainty about its exact composition.

It is also known as *Avanturine Feldspar*, and *Sunstone*.

Crystalline system the sixth, or doubly oblique prismatic. Specific gravity 2.6. Hardness equal that of orthoclase ; more or less translucent. Colour white, gray, or greenish. Fuses more easily than orthoclase or albite.

35. *Muscovite*, *Biaxial*, or *Potash Mica*, the composition of which is stated as one equivalent of trisilicate of potash to three of tribasic silicate of alumina $= (KO, 3\,Si\,O^2) + (Al^2\,O^3, Si\,O^2)$, part of the potash being replaced by lime and the protoxides of iron and manganese, and

part of the alumina by sesquioxide of iron, manganese, or chromium. One analysis gives—

Potash	10.09
Protoxide of iron	1.50
Sesquioxide of iron	3.35
Alumina	37.36
Silica	47.70
	100.00

Crystalline system the fifth or oblique prismatic. Specific gravity about 2.9. Hardness between gypsum and calcspar. Transparent, colourless, or light-coloured with metallic pearly lustre. Fuses with various degrees of facility to a turbid glass. Often contains fluorine.

This is the ordinary variety of mica. When it contains chrome it is known as *Fuchsite.*

36. *Tourmaline,* or *Schorl,* is a combination of a double silicate, with a borate, but the analyses are so varied and indefinite as not to be reducible to a common formula. The following is an example—

Soda	4.99
Protoxide of magnesia	2.85
Protoxide of iron	2.81
Sesquioxide of iron	6.27
Alumina	39.72
Silica	39.65
Boracic acid	3.71
	100.00

Primary form an obtuse rhombohedron of the third system. Specific gravity 3. to 3.3. Softer than quartz. Every degree of transparency, from perfect clearness to complete opacity ; and is variously coloured. Before the blow-pipe swells up and fuses to a slag.

37. *Porcelain Spar*, a combination with a chloride, consists of four equivalents of the double silicate of lime and alumina with one of chloride of sodium.

38. *Lithia Mica*, or *Lepidolite*, a combination with a fluoride, consists of two equivalents of monosilicate of lithia, three of two-thirds silicate of alumina, and one of a combination of fluoride of potassium and terfluoride of silicon, the peroxides of iron and manganese partly replacing the alumina.

The following is the calculated analysis :—

Potash	8.72
Lithia	5.32
Alumina	28.48
Silica	51.55
Fluorine	5.93
	100.00

Specific gravity about 2.9 ; softer than calcspar. Transparent or translucent. Fuses very readily.

The Reverend Professor Haughton has lately shewn that two varieties of mica, hitherto supposed to be of rare occurrence, are the two which occur abundantly as the constituents of the Leinster granite. These are the two micas known as Margarodite and Lepidomelane.

39. *Margarodite* (from Margaron, a unio or pearl) or *Pearl White Mica*, of which the following is the mean composition, as deduced from four analyses of specimens from different localities by Professor Haughton :—

Silica	44.58
Alumina	32.13
Peroxide of iron	4.49
Lime	0.78
Magnesia	0.76
Potash	10.67
Soda	0.95
Protoxide of iron	0.07
Loss by ignition	5.34
	99.77

It is biaxial. Its specific gravity is stated in books as 3.0 to 3.1. It is generally pale greenish-white, with a pearly lustre.

40. *Lepidomelane*, or *Black Mica* (name derived from "lepis," a scale, and "melas," black.)

Silica	35.55
Alumina	17.08
Peroxide of iron	23.70
Lime	0.61
Magnesia	3.07
Potash	9.45
Soda	0.35
Protoxide of iron	3.55
Protoxide of manganese	1.95
Water	4.30
	99.61

It is uniaxial, of a brownish-black colour, and metallic lustre.

Its specific gravity is stated at 3.0.

The descriptions of the forty minerals now given will be sufficient for reference in studying the composition of almost all rocks, which is the object we have in view. For general purposes, indeed, it is enough to consider the silicates as forming four groups of minerals, namely—1*st*, The Augites or Hornblendes; 2*d*, The Feldspars, subdivided into, 2 *a*, The Bisilicated, 2 *b*, The Trisilicated; 3*d*, The Micas; and 4*th*, The Zeolites.

1st. The Augites or Hornblendes are essentially silicates of magnesia mingled with silicates of lime, iron, or other substances which are more active fluxes to the silica than the magnesia, and make the whole easily fusible.

2d. The feldspars are essentially silicates of alumina mingled with silicates of potash, of soda, or of lime, which act more readily as a flux to the silica than the alumina does. Orthoclase (potash or common feldspar), Albite (soda feldspar), and Oligoclase, are the most highly silicated varieties of the group, Labradorite, Anorthite, and Rhyacolite are less highly silicated, containing a larger proportion of alumina, and also of the more fusible bases, which consist either wholly or in part of lime, and rarely or never of potash. The first three in the commonly received nomenclature would be called trisilicates, and the three last bisilicates. In the nomenclature proposed by Dr. Sullivan, the former would be considered as mixtures of monosilicate of alumina and trisilicates of the other bases, while the latter would contain a basic silicate of alumina and bisilicates of the other bases.

Leucite differs in composition from Orthoclase only in its containing a simple silicate of potash instead of a trisilicate.

Albite, Oligoclase, and Rhyacolite, agree in containing soda; sometimes partly replaced by potash or even by lime.

Labradorite and Anorthite (the latter of which seems to have nearly the same composition as Scapolite) are essentially the lime feldspars. Labradorite occurs as a distinct mineral abundantly in North America, but is often present, or supposed to be present, in many of the more basic igneous rocks in conjunction with Augitic or Hornblendic minerals with or without Zeolites.

3d. The Micas are frequently conspicuous in rocks, but their presence can hardly be considered so essential as that of the minerals of the preceding groups. Mica often occurs as a mere subsidiary constituent, either appearing in a rock which is usually devoid of it, or disappearing from a rock which usually contains it, without causing any change of name in the rock, which is spoken of as being "with," or "without mica." In other cases, however, the mica is looked upon as an

essential constituent, and the rock takes a new name when the mica is absent or is replaced by another mineral.

Mica is more abundantly and essentially developed in highly altered rocks than in any other, but is then not often completely crystallized.

Dr. Sullivan has suggested the probability of Micas having sometimes their peculiar metallic lustre and minute subdivision into transparent or semi-transparent plates, rather in consequence of physical structure than of chemical composition.

4th. The Zeolites are so called from the Greek word (zeo) to boil, in consequence of their intumescence before the blow-pipe. This is caused by the water which they contain. They are all hydrated minerals, most of them hydrated feldspars, though some so called Zeolites do not contain any silicate of alumina.

Analcime, Natrolite or Mesotype, Thomsonite or Comptonite, Stilbite or Desmine, Chabasite, etc., are Zeolites.

They are often found crystallized in the cavities of some igneous rock, and are supposed to be mixed up with other minerals in the composition of other igneous rocks.

CHAPTER III.

ON THE ORIGIN, CLASSIFICATION, AND DETERMINATION OF ROCKS.

A DESCRIPTION of what constitutes a true mineral has been already given in chapter 1. A rock may be described as follows.

A *rock* is a mass of mineral matter consisting of many individual particles, either of one species of mineral, or of two or more species of minerals, or of fragments of such particles. These particles need not at all resemble each other either in size, form, or composition; while neither in its minute particles, nor in the external shape of the mass, need a rock have any regular symmetry of form.

Geologists are accustomed also to include under the term rock, all considerable accumulations of mineral matter, whether they be hard or soft, compacted or incoherent. In this sense soft clay, loam, or loose sand, may be called "a rock."

Mineralogy may be studied simply as a branch of Natural History, and minerals looked upon merely as natural objects, having certain external properties which enable us to distinguish them from each other, and arrange them in a certain order, according to some principle. By help of this arrangement we might identify any particular mineral laid before us, and consequently refer to what is known of its chemical composition, and other qualities.

In order to apply mineralogy to geology, however, we must study rather the genetic relations of minerals, that is to say, we must endeavour to discover their modes of production, and the circumstances which were necessary, or conducive, to their appearance in the positions and in the combinations in which we now find them. This is the object we have had in view in the brief abstract we have just given of a part of chemistry and mineralogy.

What has been there given will enable the student to reason, to a certain extent, on the origin of rocks; and to draw certain conclusions as regards the relations of those mineral constituents, at all events, which are essential to their existence—those which so far enter into their mass as to make them what they are, and the abstraction of which would make them something different.*

* Bischof's Chemical and Physical Geology, translated for and published by the Cavendish Society, is the largest and most complete work on the Application of Mineralogical

Crystallization.—One of the most obvious properties of minerals is their crystallization. All crystals are, as it were, built up of minute crystalline particles of like forms, and have been produced by the successive external additions of these minute particles.

It is clear, then, that these particles must have been free to move and arrange themselves; in other words, they must have been in a *fluid* or *nearly fluid* state. But this fluidity may have been the result either of *solution* in water or other liquids, or of *fusion* by heat. Whenever, then, we find a crystal or a mineral particle that has an internal crystalline structure, we may feel assured that it has once been either *dissolved* or *melted*.

But if this be true as regards individual crystals or crystalline particles, it must be true also of rocks that are made up of such crystals or such particles.

Now we have seen that some minerals, as, for instance, Calcite or carbonate of lime, are readily soluble in water containing carbonic acid gas, or in liquid acids; if, therefore, we meet with a rock composed of crystalline particles of carbonate of lime, we should naturally suppose that it had once been dissolved in acidulous water and deposited from that solution.

The solid acid Silica is also soluble in water containing carbonic acid gas or some other substances, and also when in certain chemical states, and in water at a high temperature.* We can, therefore, easily understand the deposition of crystals of silica or quartz from aqueous solutions.

For the production of many silicates, however (as, for instance, the artificial silicates porcelain, slag, and glass), great heat is necessary, and they are formed only during fusion. Most of the natural silicates are practically insoluble in water, or in any other fluids which are found abundantly in nature.

When, then, we meet with rocks composed altogether of crystals, or crystalline particles, of such silicates, we naturally conclude that those rocks were once in a state of fusion from heat.

But in each of these cases there are gradations from rocks in which the crystalline particles are large and distinct, through others where they become less and less till they are only discernible with a lens, into some which appear quite *compact* and homogeneous. This gradation

Chemistry to Geology. Much of it is excellent, but unfortunately the author has allowed his mind to be warped by an old-fashioned prejudice against what he calls the "Plutonic Theory," so that he is not always entirely trustworthy.

* Mr. Jefferys shewed (Reports Brit. Assoc., vol. x.) that the vapour of water, at a temperature above that necessary to melt iron, dissolved silica, even attacking compact undivided minerals; and that a jet of such steam containing dissolved silica deposited a *snow* of quartz crystals as it cooled on escaping from the vessel.

teaches us that what is true of the crystalline rocks may also be true of *compact* rocks of the same mineral composition, and that, therefore, crystalline and compact limestone, quartz crystals, and compact flints, may equally have been dissolved in water, and crystalline and compact silicates have equally been melted by heat. In the latter case the artificial silicate glass again assists us, since the very same mass which, if cooled under given circumstances, will form a perfectly homogeneous transparent glass, will, if allowed to cool more slowly, become opaque, and stony, and ultimately begin to granulate, that is, its constituents will combine with each other in order to form distinct crystalline minerals in the mass.

Chemical Rocks.—Many rocks, then, have been chemically formed, that is, have consolidated from fusion or solution in obedience to chemical laws. Those that have become consolidated from fusion we may call Igneous rocks; those that have consolidated from solution Aqueous rocks.

Chemically-formed Aqueous rocks may be either crystalline or compact.

Chemically-formed Igneous rocks may be either crystalline, compact, or glassy.

Both kinds may have occasionally concretionary, nodular, sparry, fibrous, or other textures, according to local modifying circumstances.

Paragenesis of Minerals.—In crystalline rocks, whether aqueous or igneous, the external forms of some of the crystals are often very imperfect and sometimes even irregular. Crystals of one mineral having been first formed prevented the regular formation of the crystals of the other minerals; or, the whole mass having crystallized together, the crystals were mutually hindered from attaining their full development by the growth of their neighbours, and all became thus locked and interlaced together in a congeries of mutually imbedded crystalline particles.*

These crystalline particles, although not perfect crystals, have yet some faces and angles of perfect crystals, being evidently formed in the position where we now find them. They are *innate* crystalline granules.

Loaf-sugar, sugar candy, crystallized alum, are familiar examples of this structure, and will serve to explain what is meant by the *innate* crystalline structure of marble or of granite.

Mechanical Rocks.—In examining the mineral structure and constitution of rocks, however, we should soon become aware of another essential difference in them. We should find many rocks the particles

* The paragenesis of minerals in chemically formed rocks is a subject that has not yet received the attention it deserves. The peculiar association of minerals, and the relative order of their crystallization, as shewn by their mutual indentation and envelopment, would, if accurately observed and described, doubtless explain much that is still obscure as regards the formation of such rocks, as also that of the contents of mineral veins.

of which were large and distinct, but not at all crystalline; or if crystalline internally, their external form would not be regular like a crystal, but exhibit evident marks of mechanical fracture and attrition, of wearing away, or rounding.

The particles of these rocks whether internally crystalline or internally compact, are not mutually embedded like those of chemical rocks, and have no such appearance of having *grown* where we now find them, but have evidently been brought together from different places, and adhere to each other, either in consequence of having been squeezed together by mechanical pressure, or because they were cemented by some other substance which serves to bind and unite them to each other.

The very form and structure of these particles shew that they are fragments of other pre-existing rocks, and have been broken off the parent mass, and worn by the action of moving water.

This water-worn form and derivative origin is very obvious with respect to such of these rocks as consist of *pebbles*, or rounded fragments of other rocks, compacted together in *sand*, which is clearly the result of the abrading process.

In many cases the very rock from which the pebbles were derived can be pointed out, and the distance, therefore, which they have been carried is known. In other cases the fact of mechanical transport is obvious, though their original site may be unknown.

From those cases where the individual constituents of the rock are large and their form distinctly visible, there is every gradation through those where they become less and less, till at length we meet with some in which the particles are not discernible by the lens. We have, then, compact derivative rocks just as we have compact chemical ones.

To all such derivative rocks we may with great propriety assign the term Mechanical, as shewing that their materials have been mechanically transported to their present sites.

The machinery employed in this transportation must clearly be either currents of water or currents of air, and the mechanical rocks, therefore, must be all either Aqueous or Aerial rocks, the latter being very few and unimportant compared with the former.

Even with regard to igneous rocks, which must in themselves be purely chemical compounds, they still may have their mechanical accompaniments, as we see in the case of the ashes, cinders, and fragments blown from the mouths of volcanoes, and these may be compacted into solid rocks, whether they fall on the land or into the water.

Organic Rocks.—There is yet another source from which some rocks are derived, inasmuch as some are found to be wholly, or almost wholly, composed of fragments of animals or plants. These rocks may be termed Organic, in the sense of organically-derived rocks.

The portions of the plants or animals may be either little altered from their original condition, or very much altered and altogether mineralized. In the first case, they are allied more particularly to the mechanical; in the latter, to the chemical rocks.

Mixtures.—As, moreover, chemical precipitates are liable from many causes to be adulterated by mechanical impurities, and mechanical deposits to be impregnated with chemically acting gases or liquids, and as both mechanical admixtures and chemical actions and reactions may play a part in the formation of rocks made of organic materials, we can easily see how all three classes of rocks may occasionally be mingled together and pass into each other, and how many aqueous rocks may have been formed by the union of two or of the three agencies, and appear to belong to one or the other class, according to the point of view from which we observe them.

Stratified Rocks.—We have now arrived, then, at the conclusion that different rocks had an aqueous, an igneous, or an organic origin, solely from the consideration of the nature of the mineral particles composing them. This conclusion, however, by no means depends entirely on such considerations. The aqueous rocks are known to be so, not only from their being composed of soluble minerals, or of minerals that have been water-worn, or of parts of plants and animals that have either lived in water or been carried down into it, but also because their materials are arranged in regular layers and beds or *strata*, obviously the result of their having been regularly *strewed* out over the bottom of the seas and lakes in which they have been deposited. They are hence often called Sedimentary and Stratified rocks.

Unstratified, Eruptive, and Intrusive rocks.—The igneous rocks, on the other hand, are known to be such, not only from their consisting of silicates which could only be formed during fusion, but also from the absence of that regular stratification which is characteristic of all rocks deposited by water. If they have anything resembling stratification, it is of that irregular kind which streams of lava possess as they flow down the flanks of volcanoes or over gently sloping ground. Many of them, indeed, are just such rocks as we see now poured forth from the mouths of volcanoes in the state of molten lava; others again are closely allied to these, and there is a regular chain of gradation from these through their whole series.

Even those which least resemble actual lava in mineral composition are found sometimes to have been injected, either in great masses into the body of other rocks, or in the form of veins and tortuous strings, into their cracks and crevices, or else to have cut through them in great wall-like sheets called "dykes," just as lava cuts through rocks in the neighbourhood or in the heart of volcanoes. Now we cannot conceive

the possibility of one aqueous rock being at the time of its formation intruded into or thrust through another, since they are all formed by the tranquil *deposition* of sediment falling through water, and coming to rest at its bottom. An intrusive rock, therefore, must by the very nature of the case be an igneous rock, and the expansive power of heat is the only conceivable origin of the force which causes it to intrude. In many cases these intruded masses have exerted just such an influence on the rock they came in contact with as great heat would have exercised. The neighbouring rocks have in fact been burnt, and are sometimes greatly altered from their original state which they still possess at a distance from the igneous rocks.

Metamorphic Rocks.—This fact, together with the consideration of the chemical actions and reactions that may be set up in the mass of rocks by the percolation of various fluids or gases, and the mechanical or chemical forces that may be brought into play by the action of pressure and other agencies, naturally disposes us to ask the question, Whether many rocks as we now see them may not be in a very different state from that in which they were originally formed? We should, on investigation, find reason to answer this question in the affirmative, and introduce another class under the head of Metamorphic (or transformed) rocks, to include those which had, by means of subsequent alteration, acquired any characters essentially different from their original ones.

Four Great Classes of Rock.—Guided by these considerations we may class all rocks whatever under the four great heads of Igneous, Aqueous, Aerial, and Metamorphic, according to the nature of the agencies by which they have been brought into their present state and position.

The Igneous are all chemically-formed rocks, but some of their varieties have their mechanical accompaniments.

The Aqueous rocks are either chemical, mechanical, or organic, those of mechanical origin being far the most abundant, although not the most important kinds.

The Aerial are all mechanical.

The Metamorphic are either those in which the original structure and composition are still obvious, or those in which those characters are altogether obscured and replaced by others, when we may speak of most of them as the schistose or crystalline-schistose rocks.

Determination of Rocks.—In examining any specimen of rock, in order to determine to which of these classes it belongs, we proceed in the following way:—Having provided a chipping-hammer, a pocket-lens, a knife, and a small bottle of dilute hydrochloric or other mineral acid,* the first thing is to form, by chipping, two fresh surfaces on the

* A pocket blow-pipe is also useful occasionally, for distinguishing some varieties of igneous rock.

specimen, as nearly as possible at right angles to each other. These surfaces are to be carefully examined, in order to see if the rock be granular or compact.

Compact Rocks.—If it be quite compact, so that no granular particles be apparent even with the lens, it should be scratched with the knife. If it scratch readily, it will either be an aqueous rock or a very much decomposed igneous one. If it requires great force to make any impression on it, but can be scratched when that force is exerted, it is probably a compact igneous rock ; if, on the other hand, it be merely marked by the steel of the knife, as if by a hard lead pencil, it is then probably a purely siliceous rock, either flint, chert, or some other form of quartz. In that case it will be of aqueous origin, but probably either part of a vein, or a nodule, or concretion formed in a rock rather than a rock itself. If a compact rock be very easily scratched, it should be tried with a little dilute acid, and if it effervesces freely it may at once be set down as limestone ; if it effervesces slowly it may be an impure limestone, or else a magnesian limestone ; and if it do not effervesce at all it will either be gypsum or a decomposed rock.

Granular Rocks.—If the rock be granular, it must first be determined whether the grains be *innate* crystalline particles, or water-worn like grains of sand. If it be coarse-grained, there will not be much difficulty in this determination. Any distinctly water-worn and rounded grain or particle, or any little pebble included in the rock, will at once decide it as of aqueous origin. Sometimes the grains may consist of broken crystals, very little, if at all, water-worn, when it might be mistaken for a crystalline igneous rock. If, however, those broken crystals be all, or nearly all, fragments of quartz, great doubt would arise as to the correctness of that conclusion, and careful search will often disclose some grain distinctly rounded, or some little fragment which has obviously acquired its present form by mechanical fracture or attrition, proving it to be of aqueous origin. Regular alternations of layers, slightly different in colour and texture, form strong evidence in favour of the rock being a stratified or sedimentary, and therefore an aqueous one.

Crystalline Rocks.—If, on the contrary, the rock be distinctly crystalline in structure, the point to determine will be whether its crystalline particles consist of carbonates or sulphates, on the one hand, or silicates on the other. If of either of the two former, it may be set down at once as an aqueous rock, if of the latter, as igneous. To determine this point the knife should be first used,—if the rock be easily scratched by the point of a knife it is almost certainly one of the two former, if very easily scratched and the scratched part do not at all effervesce with acids, it is probably gypsum. If the scratched part instantly boil

up when acid is applied to it, it is certainly some kind of limestone. If it effervesce slowly and have a pearly lustre and gritty feel, it is probably magnesian limestone.

If the particles be neither carbonates nor sulphates they will almost certainly be silicates and the rock be an igneous one. It will then be necessary to determine the kind of igneous rock by discovering the nature of the minerals; whether in the first place there are any particles of free silica or quartz among them, and whether the remaining particles consist of hornblendic, feldspathic, micaceous or zeolitic minerals, or what mixture of these, and in what proportions. This will be done either by recognizing them by their characteristic external appearance, by determining the angles formed by their facets and therefore the form of their crystals, or if neither of these methods be possible, by chemical analyses, either of the separate crystals, or if that be not possible, of the whole rock, which will at least tell us what possible combinations the substances contained in the rock might form, and what combinations would be impossible, and thus approximately fix the class to which the rock must belong.

Platy Rocks.—If the rock have a very decided platy structure, so that a blow with the hammer causes it to split much more readily in one direction than in any other other, with a tendency to separate into many thin plates,—the question which arises is, whether it be a mere aqueous rock formed by the successive deposition of many thin laminæ, or whether it be a metamorphic rock. If the former, it will probably be soft and clayey, and the plates before the rock be split will run parallel to and coincide with layers of different colour, texture or grain.

Metamorphic Rocks.—If, however, it be a metamorphic rock, it will probably be hard, and the plates more or less firm after separation from each other. If the faces of these plates be dull and earthy looking, it is probably a slate or "cleaved" rock. If however the faces glitter with a metallic lustre, and the rock have a crystalline, or semi-crystalline texture, it will then be a schistose or crystalline-schistose metamorphic rock.

The student will do well to procure, and to examine with lens, acid, knife, and hammer, specimens of the most common forms of the minerals, Quartz, Calcite, Gypsum, Feldspar, Hornblende and Mica, and endeavour to recognize them in any of the common rocks, such as Granite, Limestone, Sandstone, Syenite, and Gypsum, by the methods here pointed out. A very little practice will enable him to do this, and he will then soon be able to recognize all the ordinary varieties of rock which he is likely to meet with, and will know how to go about the determination of others when they occur.

CHAPTER IV.

IGNEOUS ROCKS.

We will commence our examination of rocks with the igneous rocks as being those which may be considered the most essentially original, and those indeed from which all others are either directly or indirectly derived.

Classification according to composition.—From what has been said before, it may be inferred that all igneous rocks without exception are composed of minerals which are silicates.

These minerals may be said to belong to two great classes, silicates of magnesia and silicates of alumina, the species or varieties of each resulting from their various mixtures with silicates of potash, soda, lime, iron, manganese, etc. The silicates of magnesia, etc., constitute the hornblendic, or pyroxenic, or augitic minerals, the silicates of alumina, etc., forming the feldspathic ones. The micaceous minerals, which we may look on as resulting from mixtures of the two, or as holding an intermediate place between them, are in reality of minor importance, so far as unaltered rocks are concerned.

The feldspars are the bases of all igneous rocks, those in which no feldspar of any kind is present being very few and unimportant, even if they exist at all. The hornblendic and augitic minerals hold the next most important place, and the volcanic and trappean rocks may be divided into two great series depending on the amount of those minerals which are mingled with the feldspars. Those rocks in which feldspar alone occurs, or in which it greatly predominates, may be called the feldspathic rocks; those in which the hornblendic or augitic minerals play a considerable part, may be called hornblendic or pyroxenic rocks. It must, however, be clearly borne in mind that feldspar, in some form or other, is always the basis of the latter, while hornblende and augite in any form are often entirely absent from the former.

The igneous rocks might also be divided into two great series, the acid or siliceous, and the basic, which would nearly coincide with the classification just mentioned, of feldspathic and hornblendic. The hornblendic or augitic minerals, may all be considered as basic minerals,

while the feldspars, as was pointed out at page 47, are separable into two groups, the more basic and the more siliceous. Now, in all rocks containing a large proportion of the hornblendic or basic minerals, the feldspars associated with them are also of the more basic kind, while in the more purely feldspathic rocks, the feldspars are of the more highly silicated group of those minerals.

Classification according to circumstances of formation.—The igneous rocks are divided by Sir C. Lyell and others into two classes—the Volcanic and the Plutonic. That classification is theoretically correct, as separating those formed at the surface, in air or water, from those formed deep in the earth; but practically we often meet with rocks that it is difficult to place with certainty in either class. It is, moreover, often advisable to avoid terms that involve theoretical or foregone conclusions. For these reasons I should prefer, with Sir R. I. Murchison and others, to arrange the igneous rocks under three heads—Volcanic, Trappean, and Granitic; taking the middle term trappean as one of convenience only, to include some that are possibly volcanic, some that are more essentially granitic, with many intermediate or undetermined rocks between the two.

Igneous rocks differ among themselves.

1st, As being made up of different minerals.

2dly, As having different textures.

The three principal varieties of textures are the crystalline (or granular), compact, and glassy.

When a rock is distinctly granular, so that the crystals of its mineral constituents are clearly discernible, they may be determined by simple inspection. In the compact and vitreous textures, however, the determination of the mineral constituents of a rock can only be arrived at by chemical analysis, which will either enable us to determine what minerals those substances in such proportions would be likely to form, or to compare the analyses with that of other specimens of which the mineral constituents were known.

It has been already stated as a known fact in the manufacture of glass, that the very same molten mass of silicates would form transparent glass,* opaque slag, or crystalline stone, according to circum-

* The formation of crystals from a state of igneous fusion, is in every respect analogous to what takes place when crystals are formed in water. It is simply the deposition of crystals from solution in a liquid that becomes solid at a high temperature, or the crystallization of that liquid itself, in the same manner as when crystals are deposited from solution in water, or that water itself freezes. . . . A glass is a liquid which, on cooling, becomes more and more viscous, and at length solidifies without undergoing any sudden or definite change in physical structure. If, however, the liquid after cooling to a certain temperature, crystallize, it undergoes a sudden and entire physical change, and the structure becomes stony.—(*Sorby on Microscopical Structure of Crystals. Geol. Journal*, vol. xiv., p. 465.)

stances. As these different conditions of texture receive different names, so may the different textures of natural substances receive different names, notwithstanding that in some cases they consist of essentially the same ingredients.

As some slags become porous, or vesicular, and thus pass into cinders, so some igneous rocks likewise assume a vesicular or cindery texture.

Amygdaloid.—When the pores or vesicles become filled with a crystaline nucleus or kernel of any mineral, either by subsequent infiltration, or during the process of consolidation, so that the dispersed crystalline patches look like almonds stuck into the mass, the rock is said to be amygdaloidal.

Porphyry.—When single detached crystals are disseminated through a compact base, or large crystals through a fine grained base, the rock is said to be porphyritic. When the amygdaloidal or porphyritic structures become so marked as to appear the most prominent characters of the rock, that rock has often been spoken of simply as an amygdaloid or a porphyry. As, however, these are incidental structures common, the amygdaloidal to several, the porphyritic to all igneous rocks, this nomenclature involves the mistake of elevating an accidental to an essential attribute ; a mistake it is better to avoid.

In the following descriptions of the igneous rocks I am largely indebted to Cotta's Gesteinslehre, to the introduction to Daubeny's Volcanoes, to the last chapter of the third volume of D'Archiac's Histoire des Progrès de la Géologie, and to the Essay on Comparative Petrology* by M. J. Durocher, Mining Engineer, and Professor of the Faculty of Science at Rennes. The new edition of Naumann's Lehrbuch der Geognsie, from which much of Cotta's matter seems to be taken, and Senft's Classification und Beschreibung der Felsarten, have also been consulted.

I.—The Volcanic Rocks.

These are spoken of under the general term of Lava. They include, however. some that would be more commonly described as trap rather than lava, and others, such as tuff and ashes, which could not strictly be called by either name.

The volcanic rocks have been classified by Abich under three heads :—*a,* Trachyte ; *b,* Dolerite ; *c,* Trachy-dolerite.

* I have used the English translation of this admirable essay made by the Rev. Professor Haughton, F.T.C.D. Published by M'Glashan and Gill, Dublin.

Since the above was written, the melancholy news of Mr. Durocher's decease has reached Dublin.

Bunsen, also, in his memoir on the volcanic rocks of Iceland, gives a similar classification, describing his *normal trachytic* rocks as one end of the series, and his *normal pyroxenic* rocks at the other end, with many intermediate varieties between the two. He states the following as the mean value of the composition of his two normal rocks, and shews that by analysing any intermediate variety of rock, and determining the proportion of any one of these ingredients (taking the silica as the easiest and best), the proportion of the other ingredients may be calculated, and thus may be determined the quantities of these two normal substances which have been mixed together to form the rock in question.

	Normal Trachytic. Trachyte.	Normal Pyroxenic. Dolerite.
Silica	76.67	48.47
Alumina and protoxide of iron	14.23	30.16
Lime	1.44	11.87
Magnesia	0.28	6.89
Potash	3.20	0.65
Soda	4.18	1.96
	100.00	100.00

The Trachytes are so called from the Greek word "trachys," *rough*, as they commonly have a rough prickly feel to the finger. They are usually light-coloured, pale gray, or white, but sometimes dark gray and nearly black. They are composed principally of feldspar, the feldspar being one of the varieties that is rich in silica, such as Orthoclase, or its varieties, and not any of those in which the bases are more abundant, such as Labradorite or Anorthite.

As trachyte is made into a class, as well as a species of rock, we may similarly elevate dolerite.

The Dolerites, so called from the Greek "doleros," *deceptive*, are usually of a dark green or black colour, weathering brown externally. They are commonly heavier than the trachytes, as containing a less proportion of silica, and a greater one of the heavier bases.

They are composed partly of a feldspathic and partly of an augitic (or pyroxenic) mineral, the feldspar being commonly one of the more basic silicates, such as labradorite or anorthite.

The Trachytes, or Feldspathic Lavas.

1. *Trachyte*, properly so called, has either a fine grained, or quite compact texture, a harsh feel, and sometimes a cellular and scorified appearance. It varies in colour from a pale gray to dark iron gray, and is sometimes reddish from the presence of iron. It is composed of a confused aggregation of crystals of feldspar, often minute and needle-shaped, but with others larger and more distinct.

This feldspar is said to be commonly potash albite (or pericline), and glassy feldspar (or adularia), in which some of the potash is replaced by soda. Crystals of mica and hornblende are often present, and sometimes even of augite, the whole either confusedly united without cement, or embedded in a feldspathic paste, either cellular or compact.

I extract here from Durocher's Essay on Comparative Petrology, as translated by Haughton the analysis' of this rock, giving the maximum, minimum, and mean of the analyses of many specimens by different experimenters, and shall do the same for the other principal types of rock.

Specific gravity, maximum 2.73, minimum 2.60, mean 2.66.

	Maximum.	Minimum.	Mean.
Silica*	78	66	72.8
Alumina	18	11	15.3
Potash	9	4	6.4
Soda	2.5	0	1.4
Lime	1.5	0	0.7
Magnesia	2	0	0.9
Oxides of iron and manganese .	2.5	0.5	1.7
Loss by ignition . .	1.5	0	0.8
			100.0

2. *TrachyticPorphyry* has seldom a scorified aspect, looking often more like a plutonic than a volcanic rock, as that of the Pic de Sancy, and the Roc de Cacadogne, of Mont Dor, which at first sight resembles granite in external appearance.

Crystals of glassy feldspar, sometimes small, but sometimes as much as half an inch long, white or flesh-coloured, are set in a compact light-coloured feldspathic paste, with brown mica, and sometimes also it is

* There is said to be a trace of titanic acid with the silica in most or all of these cases.

said with crystals of quartz.* Many varieties of trachytic porphyry contain a number of very small globules, which seem to consist of melted feldspar, having often in their centre a little crystal either of quartz or mica. The assemblage of these globules leaving minute cells between them, sometimes gives to the rock a scorified aspect"—(Daubeny). Chalcedony occurs in small geodes,† and sometimes intimately mixed with the paste in which the crystals are embedded.

Specific gravity, maximum 2.65, minimum 2.52, mean 2.58.

	Maximum.	Minimum.	Mean.
Silica	75	68	72.8
Alumina . . .	14	13	13.5
Potash . . .	8	3	4.9
Soda	7	1.5	4.2
Lime	1	0	0.5
Magnesia . . .	2	0	0.7
Oxides of iron and manganese .	3	1	1.7
Loss by ignition . .	5	0	1.5
			99.8

3. *Pearlstone* is composed of a number of globules from the size of a nut to that of a grain of sand, of a vitreous, or enamelled aspect, and pearly lustre, adhering together without any paste. These sometimes lose their lustre and size, and pass into a compact stony mass, or change into globules of feldspar, compact, or radiated—the whole rock being composed of them. Many variations occur; the whole sometimes becoming fibrous, cellular, spongy, and passing gradually into pumice.

Trachytic porphyry sometimes passes into pearlstone by insensible gradations, just as we shall hereafter see that felstone is sometimes porphyritic and sometimes nodular and concretionary.

4. *Domite* is a grayish white, fine grained, compact, earthy, and often friable variety of trachyte. It frequently contains flakes of brown mica. It appears to be a decomposed trachyte, in which the feldspar is affected, but the mica not. The passage of muriatic (hydrochloric) acid is, by some, supposed to have effected this transformation. It is a remarkable rock, but not one of general occurrence, being nearly confined to the district of the Puy de Dome, in France.

* See Naumann's Lehrbuch der Geognosie, 1st vol. p. 781.

† Geodes are rounded concretions, generally hollow, and containing crystals. They are sometimes called "potatoe stones" from their size and shape.

5. *Andesite ;* a trachytic rock, found in Chimborazo and other parts of the Andes ; has white crystals resembling albite in a crystalline base of a dark colour. It has various degrees of compactness and consistency, and has a coarse conchoidal fracture. Small crystals of glassy feldspar occur, though rarely, but those of hornblende are common ; and augite is also present sometimes. From the predominance of hornblende it sometimes passes into a diorite or greenstone.

6. *Clinkstone or Phonolite* is a compact homogeneous rock, with a scaly or splintery fracture, sometimes conchoidal, of a grayish green, or ashy gray colour, both weathering white externally. It is often rendered porphyritic by scattered crystals of glassy feldspar, but these are commonly not very distinctly separable from it, appearing only as brilliant surfaces here and there in the mass. Hornblende, augite, and magnetic iron are rare in it. According to Gmelin it consists of a mixture of glassy feldspar, with a zeolite in variable proportions. It may, therefore, be formed from trachyte by the addition of sea-water ; the soda of which, combining with some of the orthoclase, would make glassy feldspar, while the water, combining with the other constituents, would form a zeolite.—(*Abich, in D'Archiac*, vol. iii., p. 604.)

Clinkstone commonly splits into thin slabs, and is often so finely laminated as to be used for roofing slate. The slabs give a metallic sound when struck with the hammer, whence its name. It is sometimes perfectly columnar ; the columns splitting across into slabs, which are also used as slates. It may, however, perhaps be doubted, whether many of the so-called volcanic clinkstones really contain water according to the definition, and whether they are not a flaggy, or laminated variety of compact trachyte.

Specific gravity, mean 2.58.

	Maximum.	Minimum.	Mean.
Silica	62	54	57.7
Alumina . . .	24	17	20.6
Potash . . .	9	3	6.0
Soda	14	3	7.0
Lime	3.5	0	1.5
Magnesia . . .	2	0	0.5
Oxides of iron and manganese .	4.5	1.5	3.5
Loss by ignition . .	3.5	1.0	3.2
			100.0

Durocher places Pitchstone or Retinite among the trachytic groups, Naumann, Cotta, and others, among the Felstones, where it is mentioned farther on. It would be very difficult to decide which arrangement is really the best.

7. *Obsidian*, or *Volcanic Glass*, is the vitreous condition of a trachytic rock. It is said to be necessary for its natural production that the rock should be composed of minerals rich in silica, "or trisilicates;" the simple "silicates," or "bisilicates" of alumina, being incapable of forming obsidian.* (*Daubeny*, p. 16, 2d edition.)

It commonly looks like coarse bottle glass, having a conchoidal fracture and breaking into sharply angular fragments, semi-transparent or translucent at the edges, black, brown, or grayish green, rarely yellow, blue, or red, sometimes streaked.

Specific gravity, maximum 2.55, minimum 2.25, mean 2.40.

	Maximum.	Minimum.	Mean.
Silica	78	61	71.0
Alumina	19	10	13.8
Potash	7	0	4.0
Soda	11	0	5.2
Lime	2	0	1.1
Magnesia	1	0	0.6
Oxides of iron and manganese	6	2	3.7
Loss by ignition	1.5	0	0.6
			100.0

8. *Pumice* is the cellular and filamentous form of obsidian or other trachytic rock, and the same remarks as to composition will apply to it.

Abich divides pumice into two groups; the cellular being dark green, poorer in silica and richer in alumina, derived from clinkstone, trachyte, or andesite; the filamentous white, containing more silica, and derived from trachytic porphyry.

* I do not at all dispute the truth of the origin here assigned to all naturally formed obsidian, but it is equally true, that basalt can be artificially converted into a substance precisely resembling natural obsidian, by simple melting and rapid cooling. Messrs. Chance of Birmingham melted the basalt of the Rowley Hills by simple heat without the addition of any foreign ingredient, and cast it into blocks and ornamental mouldings for architectural purposes. Portions which were allowed to cool rapidly, formed obsidian, undistinguishable by any external character from that of volcanic districts. Specimens may be seen in the Museums of Jermyn Street, London, and Stephen's Green, Dublin.

It is in fact the froth of a lava, its porous and filamentous characters being due to the escape of gaseous matter through it. Owing to this porous and vesicular character it swims on water, but its true specific gravity when pounded, varies from 2.0 to 2.53, the mean being 2.30.

	Maximum.	Minimum.	Mean.
Silica	77.0	61.0	68.8
Alumina	18.0	10.0	14.0
Potash	6.0	1.5	3.7
Soda	11.0	0.0	6.0
Lime	2.0	0.0	1.1
Magnesia	1.0	0.0	0.6
Oxides of iron and manganese .	4.5	0.5	3.2
Loss by ignition . .	4.0	0.5	2.6
			100.0

The Dolerites, or Augitic Lavas.

9. *Dolerite.*—A crystalline, granular, distinct mixture of labradorite and augite with some titaniferous magnetic iron ore, and also often with some carbonate of iron and carbonate of lime. General colour, dark gray.

Specific gravity, maximum 3.10, minimum 2.85, mean 2.95.

	Maximum.	Minimum.	Mean.
Silica	55	45	51.0
Alumina	16	12	14.0
Potash	1	0	0.2
Soda	5	2	3.4
Lime	13	7	10.0
Magnesia	9	3	5.5
Oxides of iron and manganese .	18	9	14.7
Loss by ignition . .	3	0.5	1.1
			99.9

The labradorite forms white or light gray tabular crystals, and the augite black columnar ones. Both can easily be distinguished by the naked eye, especially in the coarser varieties. The magnetic iron forms small octahedral scarcely visible grains, which can be recognised only by the magnet.—*Cotta.*

Naumann and Cotta mention a variety from Aulgasse near Siegburg, which contains 28 per cent of the carbonates, three-fourths of that being carbonate of iron.

Granular crystalline, porphyritic and amygdaloidal varieties of the rock occur.

10. *Anamesite* is properly only a fine-grained dolerite, so fine-grained that we can only distinguish the fact of the granular texture, and no longer recognise the individual minerals. Its colour is dark gray or greenish or brownish black. It forms the intermediate step between dolerite and

11. *Basalt*, which is a compact, apparently homogeneous, nearly or altogether black rock, with a dull conchoidal fracture. It often contains crystals or grains of augite, olvine, or magnetic iron, and is sometimes vesicular or amygdaloidal.*

Specific gravity, maximum 3.10, minimum 2.85, mean 2.96.

	Maximum.	Minimum.	Mean.
Silica	53	42	48.0
Alumina	18	10	13.8
Potash	3	0.5	1.5
Soda	5	2	3.0
Lime	14	7	10.2
Magnesia	10	3	6.5
Oxides of iron and manganese	16	9	13.8
Loss by ignition	5	1	3.2
			100.0

The knowledge of the composition of basalt dates from 1836, when Gmelin shewed that it was like phonolite, an intimate mixture of one

* According to Cotta, the rock of the Giant's Causeway, etc., in the north of Ireland, ought to be called anamesite rather than basalt. According to Senft the basalt of the Rowley hills in Staffordshire is melaphyr, as is also the toadstone of Derbyshire. I fear that these determinations may be due to the preconception that basalt proper could not occur in the older rocks rather than to any sounder reason.

part that was decomposable in acid and another not decomposable. The decomposable portion is partly of the nature of a zeolite, partly of that of labradorite ; the undecomposable portion is augite.—*Cotta.*

Basalt, therefore, as it contains water in its zeolitic portion, bears the same relation to dolerite that clinkstone does to trachyte.

The three rocks above mentioned differ rather in texture than in mineral composition. In the two following rocks another feldspathic mineral is substituted for the labradorite.

12. *Nepheline Dolerite* is a crystalline granular mixture of nepheline, augite, and some magnetic iron.—*Cotta.*

13. *Leucite Rock* is a crystalline, granular, porphyritic-like, or even a compact, aggregate of leucite, augite, and some magnetic iron ; generally gray.—*Cotta.*

Trachy-dolerite, or Intermediate Lavas.

These rocks, from their very nature, do not admit of any precise definition or nomenclature. The rocks already named and described are mixtures of various minerals. When those mixtures are in anything like definite proportions, and the minerals are well characterized, the rocks assume a particular character, and are capable of definition. When, however, the mixtures become indefinite, and the minerals begin to pass one into another, or are so intimately blended that they cannot be distinguished, attempts at definition only lead to confusion instead of order, and encumber the memory rather than assist it.

Instead of separating these blending rocks, then, and distinguishing them by different names, it is better to unite them under one term, such as that proposed by Abich, of—14. Trachy-dolerite.

Neither is this a mere evasion of a difficulty, since the things themselves are so similar both in substance and in origin, that the creation of distinct names would be merely making distinctions where no real or essential difference exists.

Abich, however, seems rather to have proposed the term of Trachydolerite in order to designate a particular variety of rock rather than to include an indefinite group, and Durocher gives it a particular composition, which, however, I omit.

The Mechanically formed Accompaniments of Lava.

15. *Volcanic Tuff* (*Volcanic Ash*) consists of the ash, dust or powder, mixed with lapilli (or rapilli), or small fragments of lava, ejected from a volcanic orifice during eruption. These materials often greatly

surpass in bulk the mere lava streams which precede, follow, or accompany them. We may include under the term also the accumulations of still larger masses, provided we can shew that they were ejected masses, and not derived by mere erosion from the waste of a cooled lava. The state of consolidation of these materials varies as much as the size and composition of their particles. Sometimes they remain quite loose and incoherent, sometimes form a solid stone. If after ejection they fall on the land, they may become compacted into a rock either by the simple pressure of their own weight, or in consequence of the percolation of water. This water may either be rain falling with the ashes, or rain or other water subsequently gaining access to them. The ash that fell on Herculaneum was mixed with water, and is therefore much more consolidated than that which covered Pompeii. If the ashes fall in the sea they become subject to the conditions under which all other mechanically-formed aqueous rocks are produced. In this case tuff or ash often contains fossil shells.

Abich describes the trachytic tuffs of the neighbourhood of Naples as of two sorts—one inferior, of a clear straw-colour, characterised by fragments of glassy feldspar, augite, and hornblende, the other, or upper tuff, being white, in thinner beds, and with much pumice.

Some geologists confine the term tuff to trachytic masses, and use the word "peperino" to designate those derived from pyroxenic (or augitic) rocks.

Immense piles of volcanic sand and gravel, and great breccias composed of large semi-angular fragments, also not unfrequently occur, which could not properly be included under the Italian word "tuff," or the English "ash," because they are more probably the result of the mere aqueous erosion of a previously existing lava than the contemporaneous accompaniment of a lava stream. Sir C. Lyell uses the term "agglomerate" in describing some of these masses of fragments of volcanic rocks.

The word "ash" is not a very good one to include all the mechanical accompaniments of a subaerial or subaqueous eruption, since ash seems to be restricted to a fine powder, the residuum of combustion. A word is wanting to express all such accompaniments, no matter what their size and condition may be, when they are accumulated in such mass as to form beds of "rock." We might call them perhaps "pyroclastic materials," but I have endeavoured in vain to think of an English word which should express this meaning, and believe, therefore, that the only plan will be to retain the word "ash," giving it an enlarged technical meaning, so as to include all the fragments accumulated during an igneous eruption, no matter what size or what shape they may be.

II.—Trappean Rocks.

It has been before said that this designation is adopted as a convenient one only, and for the same reason I would extend it. The word "trap" has hitherto been considered to be strictly applicable only to hornblendic or augitic rocks. Naumann uses it as a synonym for basalt ; and Senft for melaphyr, and what he calls basaltite. It is derived from the Swedish *trappa*, a stair, those rocks being supposed usually to assume a step-like form. The term, as thus derived, is, however, no more exclusively applicable to the hornblendic than to the feldspathic igneous rocks, and has often been used vaguely to designate any igneous rocks which could not be said to be distinctly granitic on the one hand, or absolutely volcanic on the other. In this vague and general sense I shall here use it, its very vagueness being its recommendation as best adapted to receive a class of rocks that do not admit of any strict definition or circumscription.

As the volcanic rocks are divisible into three heads, feldspathic, augitic, and intermediate, so we may conveniently divide trappean rocks into three similar heads, feldspathic, hornblendic, and intermediate. For the two first of these, the general designations, Felstone and Greenstone may be used. Felstone will comprise the siliceous traps, as trachyte does the siliceous lavas, and greenstone, the more basic traps, as dolerite includes all the more basic lavas. The blow-pipe comes here into play as a good practical means of distinguishing between the varieties of trap, as the more readily fusible varieties will almost certainly belong to the basic class rather than the siliceous.

Felstone or Feldspathic Traps.

16. *Felstone* is a name taken from the German *Feldstein*, and proposed by Professor Sedgwick to designate a class of igneous rocks to which many titles have been given, but which have not, till lately, been properly examined and described. Compact feldspar, petrosilex, and cornean, are among these names, as well as the hornstone of some geologists, though that name has also been applied to chert, and to altered clay rocks. The Germans describe this rock under the head of Porphyry or Felsite porphyry, thus assuming an accidental variety of structure as an essential character. Any one who had mapped whole mountains and great districts of it, as the Officers of the Geological Survey have done in Wales and Ireland, would have felt the necessity of having a name to distinguish the rock itself, whether it was compact, as it usually occurs, or crystalline, or porphyritic.

Felstone is a compact, smooth, hard, flinty-looking rock.

It has two principal varieties ; the pale green passing into a greenish or yellowish white, and the blue or gray varying from pale to dark gray. The gray or blue variety weathers white, its external margin being white sometimes to the depth of a line, sometimes to that of an inch or two. Some blocks that appear wholly white have a small blue patch in the centre. The green, or greenish white variety is often very translucent at the edges ; the gray is commonly opaque. The fracture is generally smooth and straight, seldom conchoidal, but in some of the blue or gray varieties it is rough and splintery. It often splits into small slabs, and sometimes, especially the green kinds, into laminæ.

The fragments sometimes ring with a metallic sound like clinkstone, and many so called clinkstones (such as those of the Roche Sanadoire and Tuilliere in the Mont Dor district, and those of the Velay) are very similar in external characters to many of the felstones of Wales and Ireland.

Durocher, under the name of petrosilex, gives the following composition of felstone.

Specific gravity, maximum 2.68, minimum 2.58, mean 2.64.

	Maximum.	Minimum.	Mean.
Silica . . .	80	68	75.4
Alumina . . .	18	11	15.0
Potash . . .	6	2	3.1
Soda . . .	6	0	1.3
Lime . . .	2	0	0.8
Magnesia . .	2.5	0	1.1
Oxides of iron and manganese . .	4.5	0.5	2.3
Loss by ignition .	3.5	0.0	1.0
			100.0

In many felstones, both in North Wales and South Ireland, lines and striæ of slightly different colours, resembling lines of lamination or deposition, can be traced through the mass of the rock, sometimes straight, sometimes more or less wavy and tortuous, like the variously hued lines and bands in a slag from an iron furnace, and resulting, probably, like them, from the motion of the mass when in a pasty and semifluid condition.

In the most smooth and compact varieties, the lens will often disclose small shining facets of crystals of feldspar, and these become larger and more numerous till we reach the completely granular and crystalline felstones. Small crystals or crystalline portions of quartz also are occasionally present in most varieties.

Sometimes the rock becomes nodular and concretionary, the nodules varying in size from that of a pea to that of a man's fist, either scattered in a compact or powdery base, or touching each other and making up almost the whole mass of the rock. The substance of these nodules is sometimes the same as that of the base, but in some instances they are hollow, and contain crystals of quartz and other minerals, and also a soft, dark green earth. In this respect it seems to resemble the rock previously described as pearlstone, though it never has any pearly or other lustre.

The Rev. Professor Haughton has lately published* the following analyses of felstones, and shewn by discussing the atomic proportions of their constituents that they may certainly be looked upon as mixtures of orthoclase and quartz, a conclusion which had previously been rather a suspicion than an ascertained fact. I have added the proportions of the two minerals at the foot, so as to comprise the whole in one table:—

	A	B	C	D	E	Means.
Silica . .	81.36	78.40	77.20	71.52	74.88	76.67
Alumina . .	7.86	11.32	6.54	12.24	12.00	9.99
Peroxide of iron	3.32	0.92	5.82	3.16	3.50	3.37
Potash . .	3.09	4.83	3.69	5.65	4.77	4.40
Soda . .	2.63	3.09	3.03	3.36	2.49	2.92
Lime . .	0.99	0.45	1.81	0.84	0.34	0.88
Magnesia . .	0.45	0.48	0.60	0.39	1.28	0.64
Protoxide of iron	...	...	...	...	0.20	0.04
Loss by ignition	...	0.56	1.12	1.20	1.20	0.81
TOTALS .	99.70	100.05	99.81	98.36	100.66	99.72
Quartz . .	45.54	37.17	40.81	20.51	26.46	34.09
Feldspar . .	54.16	62.32	56.07	76.65	73.00	64.44
TOTALS .	99.70	99.49	96.88	97.16	99.46	98.53

* In a paper, On the Lower Palæozoic Rocks of the South-East of Ireland, by Professor Haughton, and J. Beete Jukes. Trans. R. I. Academy, vol. xxiii.

A was from Ballymurtagh in the Vale of Avoca, county Wicklow, from a depth of two or three feet in the rock, obtained by blasting, natural colour pale grayish green, weathering white.

B From Carrickburn, county Wexford, pale grayish green, weathers quite white, becomes in places nodular concretionary, having balls from one to three inches in diameter.

C Bonmahon, county Waterford, pale greenish gray, stratified in some places, in others columnar, translucent on edges.

D Benaunmore, near Killarney, columnar, greenish gray, compact with facets of feldspar and globular specks of quartz.

E The rock called Pits Head, between Beddgelert and Caernarvon, North Wales, pale green, semi-translucent, with facets of feldspar.

D is embedded in rocks of Old Red Sandstone, surrounded with great beds of "ash" of the same composition as itself. The others are all included in Lower or Cambro-Silurian rocks, generally associated with similar "ashes," or "felstone tuffs."

If we compare these analyses of felstone with those previously given of trachyte and trachytic porphyry, we should be struck with their resemblance. We may certainly say that some of the more highly silicated trachytes would include some of the less highly silicated felstones. It is distinctly stated by Naumann (Lehrb. der Geog. vol. i. p. 611) that according to Abich's researches, Trachytic porphyry is an intimate mixture of Sanidine, of Albite (or Orthoclase), and free Silica, which latter is present to an amount of 25 or 30 per cent; which accounts for the frequent appearance of crystalline granules of quartz.

There is, therefore, no essential difference in composition between such a variety of Trachyte and some of the Felstones.

The most usual form of Felstone is one which is perfectly compact, sometimes as much so as a porcelain without the glaze. In other cases a few half-formed facets of feldspar will be seen glancing here and there in the mass. It passes then into a variety in which crystals of feldspar become numerous, and from that into a granular aggregate of crystals of feldspar and quartz, or a rock which is sometimes called a quartziferous porphyry (quartzführender porphyr, porphyre quartzifere).

This latter rock is known in Cornwall frequently to occur in the form of dykes, which are called "elvans," and it appears to me that the term "elvanite" might be adopted with advantage instead of the more cumbrous designation of "quartziferous porphyry." This rock forms one of the intermediate gradations between Felstone and Granite.

When in a ground mass or base of compact felstone, distinct crystals of Feldspar lie scattered about, the rock then becomes a prophyritic Felstone, or Felstone porphyry. It not unfrequently happens that the

scattered crystals of feldspar are of a different colour from the base, and the rock may then be used as an ornamental marble, and spoken of simply as Porphyry.*

In the Report of the progress of the Geological Survey of Canada for the year 1858, some White Traps are spoken of as a kind of trachytic rock, and analyses given of them by Mr. Sterry Hunt, from which they seem to be certainly felstones.

17. *Pitchstone* or *Retinite* appears to be a variety of felstone, having a more vitreous character, and a resinous lustre; whence it derives its name. It is of many colours, varying from black to green, gray, and yellow. It might perhaps be called the obsidian of felstone.

Some pitchstones are varieties of trachyte rather than of felstone, and occur about volcanoes; these may perhaps be looked upon as stony obsidians. In other places, however, pitchstone occurs under circumstances which would cause it to be looked upon as a trap rock rather than an actual lava.

Durocher gives it the following composition.

Specific gravity, maximum 2.36, minimum 2.31, mean 2.34.

	Maximum.	Minimum.	Mean.
Silica	74.0	62.0	70.6
Alumina	17.0	11.0	15.0
Potash	6.0	0.0	1.6
Soda	3.0	1.5	2.4
Lime	1.5	1.0	1.2
Magnesia	2.0	0.0	0.6
Oxides of iron and manganese .	4.0	1.0	2.6
Loss by ignition . .	8.5	0.0	6.0
			100.0

Clinkstone is frequently spoken of as a trappean as well as a volcanic rock, but it is probable that many of the rocks so described would not come within the definition of clinkstone given before, and are only platy, flaggy, and laminated (perhaps even "cleaved") varieties of felstone. Other true trappean clinkstones, however, are probably the hydrated varieties of felstone, just as volcanic clinkstone is a hydrated trachyte.

* The literal meaning of the word "porphyry" is purple, because the earliest used stones of this description had their prevailing hue of a deep red.

Greenstone, or Hornblendic Trap.

Greenstone is an old and well-known name for a numerous and important class of trappean rocks. It is a translation of the German *Grünstein*, and may be taken as synonymous with the French *Diorite*.

20. *Greenstone* consists of a mixture of feldspar and hornblende, varying in texture from a fine-grained compact rock, in which the crystalline state of the minerals is barely discernible with a lens, to a coarsely crystalline aggregate. Its colour is generally a dull green, varying from light to dark green, sometimes almost black. In some varieties, on the other hand, where the feldspar is very white and in great quantity, the rock might be described as white speckled with dark green spots. It weathers to a dull dark-coloured brown, the weathered blocks being generally massive and well rounded, and covered with patches of white lichen. On breaking open the weathered part of a greenstone and testing the rock with acid, we almost invariably find that it will effervesce along the inner border of the weathered portion. Many greenstones, also, even when apparently unweathered, effervesce with acids along the minute cracks and pores in the mass.

The feldspar of greenstones is commonly presumed to be albite, or oligoclase, but it is generally difficult to determine its variety with precision; in some of the rocks which come under this head augite or hypersthene, or some similar mineral, is substituted for hornblende. Mica, of a dark brown colour, sometimes occurs (as in some of the Wicklow greenstones) either in distinct plates, or as coating the surfaces of small crevices or those of the other crystals.

M. Delesse says that many rocks hitherto classed as greenstone contain no hornblende, their green colour being the result of the greenness of some of the feldspar composing them. These, then, would probably come under the head of one of our crystalline felstones.

Greenstone, like felstone, becomes sometimes porphyritic, in consequence of one or other of its constituents forming distinct crystals in a compact mixture of the rest, or larger disseminated crystals in a fine grained crystalline base. When the greenstone is quite compact and dark coloured, it is not, perhaps, very easy to distinguish it from basalt by any external characters.

The preceding description of greenstone is sufficiently general to include a number of rocks which have received different particular designations from different German and French authors.

Durocher includes among his basic rocks four varieties, which may be called trap rocks, as distinguished from the others, which may be classed as lavas. These we may include under the general name of Greenstone, and look on them as varieties of that rock.

Diorite, a coarse or fine-grained mixture of albite (or oligoclase) and hornblende, and therefore a typical greenstone. When the hornblende greatly predominates, it is called by Naumann *Amphibolite.*

Both Senft and Naumann say that it often contains crystalline grains of quartz ; if so, it is no longer a basic rock, but becomes, to all intents and purposes, a *Syenite*, and should therefore be no longer spoken of as either *Diorite* or *Greenstone.* They say also that in some Diorites the albite is replaced by labradorite, or even by anorthite.

The orbicular diorite of Corsica (sometimes called Corsican granite) is a remarkable variety of the rock.

Durocher gives the following as the composition of Diorite :—

Specific gravity, maximum 3.20, minimum 2.80, mean 2.66.

	Maximum.	Minimum.	Mean.
Silica	60	48	53.2
Alumina	20	13	16.0
Potash	2	0.5	1.3
Soda	3	1	2.2
Lime	9	3	6.3
Magnesia	10	2	6.0
Oxides of iron and manganese . .	20	10	14.0
Loss by ignition .	2	0	1.0
			100.0

Diorite often becomes porphyritic, large crystals of hornblende or albite, or both, appearing in a fine-grained base of Diorite.

Euphotide, *Gabbro*, *Serpentinite*, *Diallage Rock*, is described as a coarse or fine-grained rock, generally of a palish green, or gray, but sometimes olive or greenish-brown colour, with sometimes a granitic, sometimes a porphyritic look.

It is composed of labradorite and the variety of hornblende called diallage. The labradorite is sometimes of the variety called Sausserite and the diallage of the variety called smaragdite, differences which affect only the lustre or colour of the rock.

Specific gravity, maximum 3.10, minimum 2.85, mean 2.95.

	Maximum.	Minimum.	Mean.
Silica	54	45	49.0
Alumina	17	12	15.0
Potash	1	0	0.3
Soda	4	0.5	2.5
Lime	14	6	9.5
Magnesia	15	7	9.7
Oxides of iron and manganese	14	8	11.5
Loss by ignition	6	1	2.5
	..		100.0

Hyperite.—This term is not used by Naumann. Senft makes it a family term, and includes under it the rocks Eclogite, Gabbro, and Hypersthenite. Durocher makes it one of his principal terms, and, I conclude, adopts it as a synonym of Hypersthenite.

Hyperite or Hypersthenite is a mixture of labradorite and hypersthene, sometimes fine grained, sometimes excessively coarse, as in St. George's Bay, Newfoundland, where I have myself seen the rock ; and where it consists of the two minerals in crystals as large as the fist. The hypersthene is a dark brown, inclining to black, and the labradorite is green, with glancing shades of blue and red. When fine grained, the rock resembles Diabase or Aphanite of a dark brownish green, or a pale green, according to circumstances.

Specific gravity, maximum 3.10, minimum 2.85, mean 2.95.

	Maximum.	Minimum.	Mean.
Silica	55	48	51.8
Alumina	16	12	14.5
Potash	1	0	0.2
Soda	3	1	2.0
Lime	9	5	7.6
Magnesia	14	6	9.3
Oxides of iron and manganese	19	8	14.0
Loss by ignition	1	0	0.6
			100.0

Melaphyre.—Senft's description of this rock is the following :—An indistinctly mixed rock, of dirty greenish brown, or reddish gray, or greenish black-brown, passing to a completely black colour, hard and tough in the fresh state—in which appear crystals of reddish gray labradorite, with magnetic titaniferous iron ore, and commonly with some carbonate of lime, carbonate of iron, and ferruginous chlorite (Delessite) sometimes in crystalline grains ; sometimes compact or earthy, sometimes porphyritic or amygdaloidal. According to Durocher it has :—

Specific gravity, maximum 2.95, minimum 2.75, mean 2.85.

	Maximum.	Minimum.	Mean.
Silica . . .	55	49	52.2
Alumina . . .	25	18	21.6
Potash . . .	3	0	1.5
Soda . . .	6	2	4.0
Lime . . .	8	4	6.2
Magnesia . . .	5	3	4.0
Oxides of iron and manganese .	12	5	9.0
Loss by ignition . .	3	1	1.5
			100.0

This is a term which may be very usefully adopted among us for those black varieties of fine-grained rock that seem intermediate between ordinary *green* greenstone and black basalt.

Besides the foregoing rocks, there are several others, some of which both Senft and Naumann group together under the head of Diabase or Diabasite.

Diabase is said to be a mixture of the feldspars labradorite or oligoclase with augite (or pyroxene), and often with chlorite, and rarely unimpregnated with carbonate of lime.

It seems to differ from diorite, therefore, chiefly in having the magnesian silicate in the form of augite instead of hornblende, and being altogether a more basic mixture, as shewn by the presence of chlorite and carbonate of lime.

It may be called augitic greenstone, as diorite may be called hornblendic greenstone.

It is said sometimes to have a porphyritic, and sometimes an amygdaloidal texture. Naumann confines the term Greenstone to Diabase.

Aphanite appears from Senft's description to be a compact or exceed-

ingly fine-grained variety of diabase, generally of a greenish-gray, greenish-white, or blackish-green colour, a litte augite or chlorite being added to the diabase mass.

Lherzolite, according to Naumann, is a coarse-grained compact aggregate of augite (pyroxene), of an olive green, brown, or gray colour, sometimes variegated in streaks or spots shading into each other.

Variolite is, according to Naumann, a compact or aphanitic greenstone (diabase) mass, in which are developed small concretions from the size of peas to that of nuts of a greenish-white or gray, or a violet-gray colour, giving it a pock-marked appearance, whence its name.

Calcaphanite.—When these grains or nodules consist of calcspar, Naumann calls the rock by this name.

Kersantite is a name of Delesse's for a micaceous diorite, consisting of oligoclase, blackish brown magnesia mica, and a little greenish hornblende. Possibly the micaceous greenstones found at Westaston in the county Wicklow might be included under this appellation. Professor Haughton (in the paper before quoted), gives the following analyses of these greenstones.

	I.	II.
Silica	52.08	57.88
Alumina	15.60	15.20
Peroxide of iron	5.75	7.50
Potash	3.80	3.03
Soda	2.92	2.67
Lime	6.52	4.81
Magnesia	8.40	6.34
Protoxide of iron	2.57	1.35
Loss by ignition	2.24	1.04
	99.88	99.82

I. is a dark greenish gray rock, with glancing surfaces of bronze mica, and alternating parallel facets of feldspar of high lustre, no hornblende being visible, the feldspar being the chief ingredient, though the mica is most conspicuous.

II. is a fine-grained crystalline rock, forming part of the same mass as No. I., made of white feldspar and mica, which is sometimes also white, but passes into a greenish amorphous mineral, which is neither hornblende nor chlorite, but apparently a leaden-coloured greenish mica, in nearly equal quantity with the white feldspar. (Trans. R. I. A., vol. xxiii. p. 619.)

To the rocks described above may be added—

Eclogite, a coarse or fine-grained mixture of green smaragdite and red garnet, and a sub-variety of the same, called

Disthene rock, from its containing the mineral disthene or cyanite, which is allied to the garnets.

It may, however, be very well doubted whether these are in reality igneous rocks. They are perhaps more likely the products of metamorphism.

Serpentine or *Serpentinite.*—We have already seen that the mineral serpentine is a hydrated silicate of magnesia. Serpentine rock is composed of that mineral alone, or of mixtures of it with other minerals, such as carbonate of lime, alumina, etc. It has been described as an igneous rock, and some varieties of greenstone may perhaps be undistinguishable in composition from serpentine; but it may well be doubted whether true Serpentine be any thing else than a metamorphic rock. See Chapter on Metamorphic Rocks, *postea.*

Durocher speaks of Serpentines as being the "degradation of basic rocks," and gives the following as their composition :—

Specific gravity, maximum 2.66, minimum 2.50, mean 2.58.

	Maximum.	Minimum.	Mean.
Silica	45.0	40.0	42.5
Alumina . . .	3.0	0.0	0.8
Potash . .	0.0	0.0	0.0
Soda	0.0	0.0	0.0
Lime	3.5	0.0	0.8
Magnesia . . .	44.0	34.0	39.5
Oxides of iron and manganese .	8.0	1.0	3.4
Loss by ignition . .	15.0	9.0	13.0
			100.0

It will at once be seen that this composition is entirely different from that of any of the truly igneous rocks.

"*White Rock*" *Trap.*—Greenstone in some cases loses its dark colours and becomes almost white. Dykes of "white rock" trap proceeding from the greenstone of the south Staffordshire coal-field look sometimes like an earthy variety of Felstone, and might, unless carefully examined, be even mistaken for sandstone, except that they send intrusive veins through the coal and other rocks, and alter them.

The late Mr. Henry determined the composition of a specimen of this "white rock" trap as follows :—

Silica	38.830
Alumina	13.250
Lime	3.925
Magnesia	4.180
Soda	0.971
Potash	0.422
Protox. iron	13.830
Perox. iron	4.335
Carbonic acid	9.320
Water	11.010
	100.073

The presence of so large a quantity of carbonic acid and water makes it appear very different in composition from any of the greenstones just mentioned, but if we regard these two substances as of subsequent introduction by percolation, and as having entered into the composition of the rock as metamorphic agents, some of the silicates having been decomposed and converted into carbonates, and others of them becoming hydrated, there will be no difficulty in supposing the rock to have formed originally part of the greenstone mass from which the dykes proceed. Disregarding the carbonic acid and water, the composition of the rock would be—

Silica	48.8
Alumina and Perox. iron	22.1
Protoxide bases	29.0
	99.9

A composition not materially differing from that of basalt or the more basic varieties of greenstone to be found in the preceding pages.

Basalt, like clinkstone, must also be enumerated among the traps as well as among the lavas, since it may be very difficult to say, with respect to some masses of basalt, that they were ejected from what might be truly described as a volcano.

Claystone, or *Wacke*, is sometimes spoken of as a trappean rock. It is probably either a compact basalt or greenstone, in a decomposed and earthy state, or an ash partially hardened and consolidated.

Mechanically formed accompaniments of the Traps.

The trap rocks, both of the felstone and of the greenstone class, like the trachytic and doleritic lavas, are accompanied by their respective "ashes" or "tuffs."

41. *Feldspathic Ash* is usually a rather coarse-grained flaky rock, with little nodular grains enveloped in the flakes It is generally of a

pale green, pale gray, or white colour. It has often a soapy feel to the touch, and might be then called chlorite-schist by many persons. The flakes may sometimes be easily detached, and are then found to be translucent, and can readily be ground down into powder. Other varieties are much harder and more compact, and there is, in fact, every gradation from a soft ash into a compact felstone, undistinguishable from solid trap, the ash having been consolidated either by pressure or by heat, or by both combined.

When decomposed, the ash has often a brown or yellow rusty stain, and it is rare to find a feldspathic ash that will not effervesce slightly with acids, either on its general surface or in its minute crevices. Some ashes, even those that have most the appearance of solid trap, shew casts of fossils, and many contain angular fragments of slate and other rocks, clearly betraying their mechanical origin. Some even contain crystals of feldspar, which make the rock look like a porphyry, until closely examined, when the crystals are found to have their angles worn, and to have been more or less weathered and rounded before they were included in the base.

Along with these also, there generally occur angular or rounded fragments of felstone, slate, or other rocks, of every size up to blocks of 6 or 8 inches in diameter; the rock then becoming a trappean breccia or conglomerate, with either a hard and compact, or a loose and flaky base.

Sand is sometimes mingled with this base; and there is then a passage from ash, through sandy ash and ashy sandstone, into pure sandstone.

The nodular concretionary structure, which I have previously mentioned as occasionally to be seen in some felstones, likewise occurs in felstone ash very abundantly, and it is not always easy to determine in these nodular concretionary trap rocks, whether the rock was originally a molten trap or an ash that was afterwards consolidated. In either case the nodular concretions are of subsequent origin, like the concretionary nodules in shales and clays. The comparatively soft and flaky base in which the nodules are enclosed may either be the original ash, or it may be part of the trap which acquired that texture on the formation of the nodules. These nodules vary from the size of nuts to that of the fist, but are sometimes still larger, and the whole mass of the rock made up of them.

42. *Greenstone Ash* is perhaps still more various in composition than that of felstone, from which it differs in being usually of a darker colour. It often effervesces with acids, and even to a greater extent than felstone ash, as we should expect from its origin.

One well-marked variety is a quite compact rock, of a pale greenish-brown hue, speckled with small black spots.

Another is a flaky coarse-grained ash, like that of felstone, but of a darker green or olive colour. This sometimes contains embedded crystals of hornblende * that have had their edges rounded and worn, together with angular or rounded fragments of other rocks.

Another variety of greenstone ash is a dark hornblende slate, passing into hornblende schist; and it is very possible that many hornblende schists, actinolite schists, etc., are metamorphosed ash-beds.

It is obvious that rocks thus made chiefly or entirely of igneous materials would more easily be metamorphosed than purely siliceous or argillaceous rocks, and would then be converted into rocks having all the appearance of trap. If they contained crystals of feldspar or hornblende, such altered rocks could not be separated from porphyries.

I would venture also to suppose, that the rocks spoken of by the Germans as Greenstone slate, or as slaty Diorite, slaty Diabase, etc., are in reality the ashes of those rocks, and believe that much of that which is called Wacke is of similar origin.

Many examples are to be found in the south of Ireland, in the parts examined by the Geological Survey, especially in the county Limerick, of these tuffs or ashes derived from greenstone, or from some basic trap rocks. They vary from the finest grained, almost porcellanic looking rock of a pale green or dull purple colour, through every gradation of texture, up to angular and rounded breccias, and conglomerates. The fragments and pebbles in these trappean breccias are either portions of trap, or fragments of limestone, sometimes of some inches in diameter, and they form great beds, several hundred feet thick, interstratified with beds of Carboniferous limestone, and surrounding bosses of trap, from which thick widely-spread flows or sheets proceed, running for many miles.

Some of these trappean ashes with pebbles of Carboniferous limestone, forcibly reminded me of the volcanic ashes in the islands of Erroob and Maer (or Darnley and Murray Islands), in Torres Straits, in which pebbles of coral limestone were included together with pebbles of the lava flows of which the islands were partly composed.

Some of the greenstone ashes and breccias in the Carboniferous rocks of Limerick, as also in the older Silurian rocks of the county Wicklow, contain fragments of vesicular greenstone such as is not known in situ anywhere in the neighbourhood. It is probable that these scoriaceous fragments are derived from the upper surface of the old trap stream when first poured out, that upper surface having been destroyed and swept away before the lower part of the trap was covered

* Near Black Ball Head, county Cork, is a cliff of such a greenstone ash, in which crystals of hornblende, three inches wide, have been seen. They are dull and worn externally, but internally quite bright and glistening.

by the deposit of the aqueous rock which now covers it. These scoriaceous pebbles are interesting, therefore, as the only relics of a former vesicular and almost pumiceous covering, which would assimilate the old trappean flows with those of recent volcanoes. (See paper on Igneous Rocks of Arklow Head.—Journal Geol. Soc. Dub., vol. viii., p. 23.)

The trappean ash of county Limerick answers precisely to the rock known in Germany as Schaalstein or Spilites, and has been described under the latter term by Mr. Ainsworth in the first volume of the Journal of Geol. Soc. Dublin.

The beds commonly known as "red ochre," which lie between the great basaltic bands of county Antrim, are unquestionably "basaltic ash," a fact of which I convinced myself in a recent examination of them. They consist of pinkish and yellowish ferruginous trappean powder, enclosing angular fragments of minutely vesicular trap, and containing in some places concretions of red pisolitic hæmatite. In other instances they pass into a brown compact earthy clay, the "wacke" of continental writers, and probably the "claystone" of Jameson, but they are all the contemporaneous accompaniments of the eruptions from which the basaltic flows proceeded, and the more minutely vesicular (almost pumiceous) fragments they contain are the more frothy parts of those flows, either blown from the orifices and falling into the sea, or swept from their surface immediately on their first cooling.

In the preceding descriptions of the volcanic and trappean rocks it has been my object to give such an account of them as may enable the student to identify the more marked varieties. It will ordinarily be sufficient for him to determine in the field whether a lava be a trachyte or siliceous lava on the one hand, or a dolerite or basic lava on the other; and similarly among the traps, whether it be a siliceous trap or felstone, or a basic trap or greenstone. The varieties of each class may very safely be left undistinguished until the specimens come to be arranged in the cabinet of classified rocks, after they have been submitted to chemical analysis, or other more exact methods of examination than can be pursued in the field.

III.—The Granitic Rocks.

It has been once or twice pointed out in the preceding pages that the volcanic and trappean rocks are readily divisible into two series, according to the relative proportions of the acid (silica), and the earthy and alkaline bases which enter into their composition.

The siliceous lavas or trachytes consist of the most highly silicated feldspars, and some of their varieties are said even to exhibit quartz in

consequence of having more silica than could be absorbed by their basic constituents. In the siliceous traps or felstones this is always the case, and the rock consists of a mixture of uncombined silica or quartz and of the most highly silicated feldspars. It would obviously be most unlikely that the more basic feldspars (bisilicates), such as labradorite, should have been produced in such rocks, since the proportionate quantity of silica present was not only enough but more than enough to have made them into trisilicates.

In the felstones proper, however, the quartz although existent rarely becomes visible, or, if it does, only appears as detached globular particles widely scattered in the mass. In the felstone and trachytic porphyries indeed, quartz is said sometimes to occur in perfect crystals of double pyramids (*Baron Richtofen Proceed. Imp. Geol. Inst. Vienna, March* 15, 1859, *as abstracted in Geol. Journal*, vol. 15), but this must be looked on as an exception to the general rule.

In all the granitic rocks, on the other hand, quartz is not only present but visible, the existence of crystalline particles of quartz, intertangled with the crystalline particles of the other minerals, being their most essential character. It is, however, remarkable that quartz never forms in granite perfect crystals, whereas the feldspathic ingredients frequently do so, and the micaceous not unfrequently. The feldspars orthoclase, albite, or oligoclase, were then solidified previously to the quartz, an anomaly to be explained perhaps by the fact of a difference between the point of fusion and the point of solidification in the minerals, and by the protracted viscosity of the quartz. This may be owing to the slow refrigeration of the mass, allowing the highly siliceous minerals to crystallize in a magma of silica, while the more rapid cooling of the porphyries and trachytes produced a mixed feldspathic paste only, in which some crystals of quartz were generated (*ib.*)

Professor Haughton has well spoken of felstone as the "glass of granite."

Granite then may be looked upon as the original rock from which the purely feldspathic or highly silicated traps and lavas have proceeded directly, the differences between them being due rather to the circumstances under which they have been cooled and consolidated, than to any essential distinction in their ingredients. It is a difference of texture, not of composition. Granite, however, may equally be looked upon as the original mass of the more basic traps and lavas, if we conceive that to an original molten mass of granite a quantity of the more fusible bases were in some way added.

There exist in nature rocks which are apparently the intermediate steps or passages from granite into two kinds of trap rocks. When a felstone becomes distinctly crystalline granular, so as to consist of an

aggregate of crystalline particles of feldspar and quartz, it only requires the addition of some micaceous mineral to become a true granite.

When, on the other hand, a greenstone is coarsely crystalline, so as to form an aggregate of crystalline particles of feldspar and hornblende, it only requires the appearance of crystalline granules of quartz to become a true syenite, which is but a modification of granite.

43. *Granite.*—True Granite, in its ordinary form, is one of the most easily described and certainly recognized of all rocks. It is a fine or coarse-grained crystalline aggregate of the three minerals feldspar, mica, and quartz. Its name is sometimes said to be derived from its granular structure, but Jameson derives it from "*geranites*," a term used by Pliny to designate a particular kind of stone.

Ordinary granite varies according to the composition of the feldspar and mica composing it, according to the relative proportions of those minerals to each other and to the quartz, and according to the size of the crystals, and the state of aggregation of the several constituents.

The feldspar of granite may be either orthoclase or potash feldspar, frequently flesh-coloured, but sometimes white; albite or soda feldspar, generally dead white; an intermixture of those two minerals; or lastly. the feldspar called oligoclase.

The kind of feldspar seems sometimes to be peculiar to the locality, the granite of the south-east of Ireland containing orthoclase only, some of that of the Mourne Mountains albite as well as orthoclase, while the Scandinavian granites have mostly oligoclase.

The mica of granite varies greatly in colour and lustre, being sometimes dark, coppery-brown, sometimes black, sometimes green, sometimes golden yellow, and sometimes a pure silvery white.

The quartz is commonly colourless or white, but sometimes dark gray or brown.

The proportions of the three constituents vary indefinitely, with this limitation, that the feldspar is always an essential ingredient, and never forms less than a third, rarely less than half of the mass, and generally a still larger proportion. Sometimes the mica, sometimes the quartz, becomes so minute as to be barely perceptible.

The state of aggregation of the mass varies also greatly, some granites being very close and fine grained, others largely and coarsely crystalline. The colours of the rock are generally either red, gray, or white; the first when the feldspar is flesh-coloured, the latter when it is pure white, the intermediate gray tints depending chiefly on the abundance and colour of the mica, but sometimes on that of the quartz.

Large and distinct crystal of feldspar sometimes occur, disseminated at intervals through the mass, giving the rock a porphyritic texture. It is then called Porphyritic Granite.

In the paper before quoted from the Transactions of the Royal Irish Academy, Professor Haughton gives a very complete account of the constitution of the largest granitic mass in the United Kingdom, that, namely, that stretches south of Dublin for a distance of seventy miles.

The following is the mean of the analyses of eleven specimens from so many different parts of the chain :—

	Maximum.	Minimum.	Mean.
Silica	74.24	70.28	72.07
Alumina	16.68	12.64	14.81
Peroxide of iron .	3.47	1.08	2.22
Potash	7.92	3.95	5.11
Soda	3.53	0.54	2.79
Lime	2.84	0.67	1.63
Magnesia	0.53	0.00	0.33
Protoxide of iron .	0.30*	0.00	0.00
Loss by ignition . .	1.39	0.00	1.09
			100.05

Professor Haughton shews that the granite having the above average composition consists of four minerals, orthoclase, two kinds of mica, and quartz, confusedly embedded in a feldspathic paste.

The feldspathic paste does not assume any definite crystalline form, and, therefore, is not considered to be entitled to the name of a definite mineral. It contains nearly 4 per cent of both potash and soda, and seems to be the superfluous matter in the original mixture which remained unused, as we may say, when the other minerals formed.

Having analysed, separately, the distinct minerals orthoclase, the white mica or margarodite, and the black mica, which he shews to be lepidomelane, and having assumed that the feldspathic paste is at all events a trisilicated feldspar (which it must be from the presence of free silica in the rock), Professor Haughton calculates the proportions of each mineral, and gets the following as the mineralogical constitution of the granite :—

Quartz	27.66
Feldspar	52.94
Margarodite	14.18
Lepidomelane	5.27
	100.05

* In one case only.

that is to say, rather more than a half feldspar, rather more than a quarter quartz, and the rest two kinds of mica.

Having established the constitution of this great mass of granite, and shewn its constancy throughout its extent, he then proceeds to examine the composition of a number of granitic bosses that protrude through the slate rocks between the main chain and the sea. These were found not only to differ in composition from the main chain granite, but to differ also among themselves, so that no two of them were exactly alike. Among nine specimens analysed from as many different localities, the per centage of silica varied from 66.6 to 80.24, that of alumina from 11.24 to 18, while in the majority of them the per centages of soda and lime were greater, and sometimes considerably greater, than those of potash. It is believed that these irregular differences resulted from the differences in the composition of the particular aqueous rocks with which the granitic masses came in contact. A portion of these rocks is supposed to have been absorbed and melted down into the granite.

In one of these detached bosses—that of the hill known as Croachan Kinshela—a specimen taken from the head of a valley as deep into the granitic mass as we could reach, shewed a composition resembling that of the main chain, while another specimen from the summit of the hill nearer the original slaty envelope of the granitic mass, deviated greatly from it in composition (Trans. R. I. A., vol. xxiii., p. 608, etc.), and contained chlorite instead of mica.

According to Durocher the following is the mean composition of granite :—

Specific Gravity, maximum 2.73, minimum 2.60, mean 2.66.

	Maximum.	Minimum.	Mean.
Silica	78.0	66	72.8
Alumina	18.0	11	15.3
Potash	9.0	4	6.4
Soda	2.5	0	1.4
Lime	1.5	0	0.7
Magnesia	2.0	0	0.9
Oxides of iron and manganese	2.5	05	1.7
Loss by ignition	1.5	0	0.8
			100.0

Comparing Professor Haughton's mean of the Leinster granite with this more general average, we learn that the granite of the south-east of Ireland contains a rather larger proportion of sesquioxide of iron replacing alumina, and of soda and lime replacing potash, than granites usually contain ; the mean quantity of iron in the Irish granite being nearly as great as Durocher's maximum, and the mean quantities of soda and lime being even greater than his maxima.

This is probably the reason why the main granite of the south-east of Ireland is so much less durable as a building stone than granite generally is.

44. *Syenite*, in its true form, is a granitic rock. It is named from the city of Syene, in Egypt, where it is formed of a crystalline aggregate of the four minerals feldspar, hornblende, mica, and quartz ; the mica being in small and uncertain quantity. We have already, however, had occasion to remark, that syenite may be formed from either felstone or greenstone, and we may look upon it therefore either as a local variety of granite, or as a passage or transition rock between granite and the traps.

True syenite, therefore, differs from granite solely in the fact of its containing hornblende instead of mica, and may be described as a crystalline granular aggregate of feldspar, hornblende, and quartz; the feldspar being generally red, and the rock mottled red and dark green, from the occurrence of hornblende. Some syenites, however, may have white feldspar.

Naumann,* Senft, Cotta, and other continental geologists, give a rather different definition of syenite. They say it consists essentially of a mixture of orthoclase and hornblende, to which oligoclase, quartz, and mica are occasionally added. According to this definition, syenite would differ from diorite solely in the difference in the feldspathic ingredient, diorite being a mixture of albite (or oligoclase) and hornblende, to which quartz and mica may also be added. This difference would hardly appear sufficient to constitute a valid distinction, and there is, moreover, this objection to it, that it is utterly unpractical. No distinctions between rocks are worthy of much notice that cannot be applied in the field, and it would be often quite impossible for any one to determine whether the feldspathic ingredient of a fine-grained rock were orthoclase or albite, by examination with the knife and the lens only.

It seems better, therefore, on all accounts to fall back on the old definition of syenite, which makes it a hornblendic granite instead of a

* Naumann, however, includes syenite in his "Familie des Granites," and not in his other "Families" of rocks.

micaceous one, the presence of crystalline particles of quartz being an essential characteristic.

This rock is probably the one called by Durocher syenitic granite, of which he gives the following analysis.

Specific gravity, maximum 2.75, minimum 2.63, mean 2.68.

	Maximum.	Minimum.	Mean.
Silica	72.0	64	69.0
Alumina . . .	17.0	12	15.0
Potash . . .	6.0	3	4.2
Soda	3.5	1	2.8
Lime	4.0	1	2.2
Magnesia . . .	4.0	2	2.6
Oxides of iron and manganese	5.0	2	3.2
Loss by ignition . .	1.5	0	1.0
			100.0

It is, however, quite possible that some rocks, the main mass of which is a greenstone, may in some places begin to shew quartz, and thus pass into a syenite ; the term Syenitic Greenstone, therefore, may often be a proper one.

The Zircon Syenite of Norway and Sweden is a remarkable variety of the rock.

46. *Eurite* is a term applied by Delesse and some others to a fine-grained crystalline aggregate of quartz and feldspar, where the mica is either absent or occurs in such minute flakes as to be invisible.

It generally occurs as veins or as local masses in other granites, and rarely, I believe, as veins traversing other rocks at a distance from granite. These, therefore, are probably veins of segregation or of injection during consolidation, and not of long subsequent formation.

Naumann and Senft, however, use the term partly for a granular felstone, and partly for a schistose variety of gneiss.

Protogine.—This name has been applied to a rock said to be a granite, in which talc took the place of mica. It was so called because it was supposed to be the *first formed* granite. The specimens of it which I have seen, appeared to me to be metamorphic rocks and no true granite, and the descriptions given by Naumann and Senft confirm this opinion.

Professor Haughton informs me, that in all the specimens of

protogine from the Alps which he has examined, the dark green mineral was not talc, but dull mica or chlorite, or some kindred mineral. I can equally affirm, that all the rocks that I saw in a traverse across the Alps in 1860, which could be classed under the head of protogine, were not granites, but only beds of granitoid rock interstratified with other highly metamorphosed beds.

Some granite seems to contain chlorite instead of mica, but as far as my own experience goes, it is only found on the upper or outer margin of the smaller masses or intrusive bosses of granite.

The same observation may be applied to the very schorlaceous granite of Devon and Cornwall, though schorl undoubtedly occurs in small detached quantities deep in some granites.

47. *Minette* is a name for a fine-grained rock, consisting principally of mica, but not having a schistose texture like mica schist.

48. *Pegmatite* is a crystalline aggregate of quartz and feldspar, in which the crystals are arranged as if with a design to produce a certain pattern, more or less resembling letters or characters (from the Greek word "pegma," a coagulation). It is sometimes called Graphic granite.

49. *Granulite* is a similar composition, in which the quartz occurs in thin flakes, so as to give a schistose texture to the mass, and is probably rather a variety of gneiss than of granite.

50. *Elvan* or *Elvanite*.—Elvan is a Cornish term for a crystalline granular mixture of quartz and feldspar, forming veins that are either seen to proceed from granite or occur in its neighbourhood, and may thus be readily supposed to proceed from it.

It has three varieties :—

(*a*.) An equably crystalline mixture of quartz and feldspar, generally fine grained. This may either be considered as a granite destitute of mica, or as a granular felstone.

(*b*.) A compact felstone base with dispersed crystals, or crystalline particles of quartz, sometimes angular, sometimes rounded, and amygdaloidal. This may be considered as a quartziferous felstone porphyry.

(*c*.) A crystalline granular base of quartz and feldspar, with dispersed crystals of either quartz or feldspar.

The feldspathic portion of these rocks is often earthy, probably from decomposition.

I would propose *Elvanite* as a good euphonious term, and as being less cumbersome than the term of Quartziferous Porphyry, for those combinations of quartz and feldspar which differ in texture from Eurite, or Pegmatite.

Hälleflinta and *Aplite* are names given by Naumann for rocks of similar character to elvans, or perhaps, especially the first, to Felstones.

Miaskite is a coarse-grained mixture of white orthoclase, grayish

or yellowish white elæolite (or nepheline, allied to scapolite) and black mica, the elæolite sometimes giving place to hornblende, and albite and quartz appearing in the rock. It belongs rather to the traps than the granites.

Gneiss distinguished from Granite.—In almost all books treating of rocks, and especially in all the continental works, it is usual to find gneiss mentioned in the same group with granite. I do not presume to deny the existence of gneissose granite, since I cannot say that the minerals forming granite may not in some cases arrange themselves with a certain degree of parallelism, and thus produce an appearance of lamination and a schistose structure in the mass. The only instance I have myself met with of such an occurrence, is at the side of a granite vein at Dalkey, near Dublin, where, however, it is only apparent for a few yards in length, and two or three feet in width. It is caused there by the parallel arrangement of the mica plates, and only becomes obvious when seen *in situ*, and it can be contrasted with the other part of the vein in which the plates are variously disposed. In detached blocks even of a foot in diameter, nobody would observe the arrangement, nor would any one think of calling the rock gneiss.

I have examined gneiss and granite together in different parts of the British Islands, in Central France, in Australia, and over large bare tracts of it excellently exposed in Newfoundland, and never found any difficulty in instantly perceiving the distinction between gneiss and granite, even where the gneiss was most granitic in composition, and where its beds were penetrated in all directions by veins of granite.

In the masses of granitoid rocks in the Alps the minerals are so confusedly crystallized, that hand specimens or even blocks, or in some instances large cliff surfaces might be considered as fairly entitled to the name of granite. When examined on a still larger scale, however, the "behaviour" of the rock, or its relation to the surrounding masses, shews it not to be an intrusive igneous rock, but a bedded or stratified one, so highly altered as to have assumed a granitic texture *in situ*, and thus to be in fact lithologically a granite, white petrologically it is only an extreme form of gneiss.

Absence of Ashes.—As the granite rocks are all hypogenous or nether-formed, that is, have all been consolidated before reaching the surface of the earth, they are necessarily devoid of "ash," or of any mechanically derived accompaniments whatever.

Proportion of Silica.—It has been remarked above, that the relative quantity of silica had a marked effect upon the nature of the rock; that among the lavas quartz only appeared in these trachyte porphyries which were beginning to resemble granite; and that among the traps it only appeared among those feldspar porphyries, which were closely

allied to, and passing into, granite, while from the true granites it is never absent. It has been attempted from this to prove that the more siliceous an igneous rock was, the more ancient it must be. Even Abich says that we may, perhaps, thus deduce a scale for the history of the formation of the earth—those rocks which contain, as essential constituents, "trisilicates"* of both their protoxide and peroxide bases being "primitive," while those which contain quartz are called "primitive plutonic," and those without quartz, "primitive volcanic."

M. Riviere also supposes orthoclase to be confined to the older, labradorite to the more recent rocks. The other bases, too, as magnesia and lime, have been supposed to characterize newer rocks than those of soda and potash, and soda itself to be newer than potash.

I would venture to suggest that these mineralogical differences depend upon space or locality rather than upon time; that the proportionate quantity of silica is referable to the depth at which an igneous rock has been cooled or consolidated, or to the nature of those it penetrated, rather than to the time at which it was formed. At great depths in the earth, pure silica itself may possibly be fused† by the intense heat there to be met with, and the most refractory silicates may be equally molten at a somewhat less depth, and consolidate or crystallize on becoming cooler a little higher, while those portions of molten matter containing a greater quantity or variety of bases which act as more perfect fluxes, may be kept fluid till they reach the surface, and thus consolidate only in the air or in the water.

Whether the more siliceous and the more basic rocks once formed part of a deep-seated homogeneous molten mass, and were merely separated from each other in their upward passage towards the surface, so that the more siliceous were first arrested and consolidated while the more basic proceeded; or whether, the whole mass being originally highly siliceous, a larger and larger proportion of the bases was acquired during the passage of the molten rock through the higher part of the earth's crust, and thus the quantity of "flux" increased in proportion as the heat and pressure diminished, may be matter for speculation. We will not now stop to consider it farther, than to warn the student not to take it for granted that the mineralogical and lithological composition or structure of any rock whatever has any necessary and determinate relation to its geological age. Granite might become solid at a temperature that would keep felstone and trachyte still fluid; and these might solidify at temperatures which would keep molten all greenstones,

* That is according to the ordinarily used chemical nomenclature. See ante, p. 20.

† It is stated by Sir J. Herschel (Outlines of Astronomy, 6th Ed., Chap. XI., Art. 592) that Parker's great lens concentrated the sun's heat to a sufficient extent to melt carnelian, agate, and rock crystal.

basalts, and dolerites, so that from the very same stream of igneous matter proceeding from the interior to the surface of the earth, the more readily fusible portions might be successively squeezed out, as it were, as the infusible ones solidified and contracted in consequence of that solidification.* This action might take place in spite of the greater specific gravity of the more fusible minerals, since the difference in the specific gravities would probably be small compared with the power of the eruptive force.

Traps and Granites the Roots of Volcanoes.—It is true, indeed, that actual subaerial volcanoes, with cones, and craters, and *coulées*, or *streams* of lava, are only known as recent geological phenomena—as either now active or as having been so during a recent geological period. But we shall see hereafter reason to believe that the preservation of any volcanic cones belonging to the more ancient periods was not to be expected. The parts preserved from destruction and denudation are the more deeply-seated portions only, the *roots*, as it were, of the volcano, the very parts which we cannot see while the volcano is active or entire, but which we do see in some (such as those of the Mont Dor) that are half ruined, and we then find these old lava roots to be essentially the same as the traps; and we have already seen that deeply formed trap is not to be separated by any hard line from granite. If, therefore, we could follow any actual lava stream to its source in the bowels of the earth, we should, in all probability, be able to mark in its course every gradation, from cinder or pumice to actual granite.

Granite passing into Trap.—Not only do volcanic districts shew trap-like or granitoid rocks near their roots, but many granitic districts exhibit passages or transitions from granites into trappean rocks. Cases have been formerly described by Drs. M'Culloch and Hibbert, and one very interesting one has lately been traced in detail by Professor Haughton. In his paper on the granites of the Mourne Mountain district of the north-east of Ireland, he shews that near Carlingford there is a granitic tract about five miles in diameter, of which Carlingford Hill is the most conspicuous feature.

In Slievenaglogh, granite composed of

Quartz	20.70
Feldspar	66.37
Mica	12.76
	99.83

* The chemist is reminded of the fact, that if a mixture of metals, as, for instance, tin, bismuth, and lead, be melted, they will, as the mixture cools, have a tendency to solidify and crystallize separately as the temperature of the mass reaches their respective melting points. This constitutes a great difficulty in large bronze castings.

passes into a granitic syenite composed of

Quartz	17.16
Feldspar	67.18
Hornblende . . .	15.40
	99.74

At Grange Nish the latter variety penetrates the lower beds of the Carboniferous limestone, and while the limestone is converted into a sugary marble containing garnets, the granitic syenite is converted into a greenstone composed of

Anorthite	85.84
Hornblende . . .	14.16
	100.00

This greenstone * passes on the summit of Carlingford Mountain into a hornblende rock.

Here we see that the granitic syenite containing a trisilicated feldspar and an overplus of silica, was, by absorbing a quantity of lime while in a state of fusion, made into a rock containing a bisilicated feldspar only, all the silica being used up in the compound, and the quartz accordingly disappearing. The lime feldspar anorthite had hitherto been supposed to occur only in volcanic rocks.—(*Geol. Journal, London*, vol. xii., 1856.)

Mr. Sorby's Observations on Granite.—Mr. Sorby published in the Geological Journal (*vol.* xiv., *p.* 453, *etc.*) a very interesting paper on the Microscopical Structure of Crystals, in which he shews that it is possible to arrive at some remarkable conclusions as to the temperature and depth at which the crystalline particles of granite and other igneous rocks were formed.

Crystals formed from warm fluid solutions, are often full of cavities which contain some of the fluid in which they were formed. If these cavities are not completely filled with the fluid, the vacuity may be taken as a measure of the shrinking of the fluid during cooling, and we may then calculate the amount of heat requisite to expand the contained fluid so as to completely fill the cavity, and thus arrive at a knowledge of the temperature of the fluid at the time the crystal was formed.

But crystals formed in *fluids by fusion* are also full of cavities which

* Professor Haughton terms this a syenite, considering the other rocks as different varieties of granite. I have, in accordance with the nomenclature previously adopted, termed the hornblendic granite a syenite, and considered the rock as becoming a greenstone or diorite when it loses its quartz.

contain some of the fused matter now become solid stone, together with vacuities, the relative size of which enables us to calculate the amount of heat requisite to melt and expand the contained stone or glass so as to fill up the whole cavity.

The effect of pressure has of course to be taken into account; the greater the pressure the greater would be the temperature of consolidation requisite for the production of cavities and vacuities in the crystals, so that the relative sizes of these when the possible temperatures of consolidation are taken into account, gives us an idea of the pressure and possible depth under which the rock was consolidated.

Mr. Sorby applies these principles to the examination of many igneous rocks, lavas, traps, and granites, and proves from them the igneous origin of all, with this remarkable result, that the fluidity of the more superficial lavas and traps was a more purely igneous one than that of the deeper seated traps and granites. The blocks ejected from Vesuvius during eruption contain water, while the lavas do not; and the crystals of the Cornish elvans, and the Cornish and Scotch granites contain both fluid and stone cavities, proving the presence of water, and perhaps also of gas, as well as the existence of great heat. Mr. Sorby says—

"On the whole, then, the microscopical structure of the constituent minerals of granite is in every respect analogous to that of those formed at great depths, and ejected from modern volcanoes, or that of the quartz in the trachyte of Ponza, as though granite had been formed under similar physical conditions, combining at once both igneous fusion, aqueous solution, and gaseous sublimation. The proof of the operation of water is quite as strong as of that of heat." He says that in some coarse granites it is impossible to draw a line between them and veins in which crystals of feldspar, mica, and quartz, seem to have been formed from solutions without any actual fusion.

It is probable that traps and lavas which proceeded from this great internal cauldron towards, or on to, the surface, would lose their gaseous and watery constituents by evaporation.

Mr. Sorby arrives at the conclusion, that if granite and elvan finally consolidated at a temperature not exceeding about 608° F., the elvans of Cornwall must have been formed under a pressure equal to that which would have been exerted by a thickness of about 40,000 feet of rock, those of the Highlands of Scotland one of 69,000. His calculations unite in giving these conclusions:—

The granites of the Highlands indicate a pressure of 26,000 feet more than those of Cornwall.

The elvans of the Highlands, one of 28,700 feet more than those of Cornwall.

The metamorphic rocks of the Highlands, one of 23,700 feet more than those of Cornwall.

If the temperature of consolidation was higher, the pressures must have been greater.

It is not intended in his conclusions to point out the absolute depths at which the rocks consolidated, since the pressure they were subjected to would arise in part from the impelling force acting from below against the superincumbent mass.

Contraction of Igneous Rocks on cooling.—Bischof has made some important observations on the contraction of igneous rocks as they pass from a fluid or glassy state to a consolidated condition.—(*D'Archiac*, vol. iii. p. 598).

He experimented on basalt, trachyte, and granite, and got the following results :—

	Volume in the state of Glass.	In crystalline state.
Basalt . . .	1	0.9298
Trachyte . .	1	0.9214
Granite . . .	1	0.8420
	In the Fluid state.	In crystalline state.
Basalt . . .	1	0.896
Trachyte . .	1	0.8187
Granite . . .	1	0.7481

From this it would appear that granite contracts 25 per cent, or a quarter of its volume, in passing from a fluid to a crystalline state, and 16 per cent in passing from a glassy to a crystalline state. These effects must have had a great importance " when the primary granites were first cooling," says M. D'Archiac ; but their importance seems to me still greater to geologists who are examining the broken and contorted rocks on the flanks of existing granite chains,* and the phenomena of intrusion which we shall hereafter meet with in such situations.

M. Deville and M. Delesse arrive at results rather different from Bischof's, and the latter gives the following table as comprising the limits within which the several rocks mentioned contract on passing from a fluid to a solid state.

Granite, leptynites, quartziferous porphyries, etc.	9 to 10 per cent.
Syenitic granite, and syenite	8 to 9 „
Porphyry, red, brown, or green, with or without quartz, having a base of orthose, oligoclase, or andesite	8 to 10 „

* I would just warn the student here, that though there may have been such a rock as primitive granite, none of the granites now known at the surface can be shewn to have an antiquity so great as that of some of the aqueous rocks with which they are associated.

Diorites and porphyritic diorites (greenstones) .	6 to 8 per cent.
Melaphyres	5 to 7 „
Basalts and trachytes (old volcanic rocks) . .	3 to 5 „
Lavas (volcanic and vitreous rocks) . . .	0 to 4 „

M. Delesse sums up his results as follows :—

"When rocks pass from a crystalline to a glassy state, they suffer a diminution of density which, all things being equal, appears to be greater in proportion to the quantity of silica and alcali, and, on the contrary, less in proportion to that of iron, lime, and alumina which they contain. In arranging the rocks in the order of their diminution of density, those which we regard as the more *ancient* are generally among the *first*, while the more *modern* are the *latter;* and in each case their order of diminution of density is almost exactly the inverse of their order of fusibility."

On this I would remark as before, that for "ancient" and "modern" might be substituted "deeply formed" and "superficially formed;" the most infusible and the most contractible rocks being those produced at the greatest depth and under the greatest pressure, while the highly fusible compounds escape to the surface, and suffer little contraction on solidification.

M. D'Archiac remarks that if granite contracts on cooling only 10 per cent, and that there be a thickness of 40,000 metres of it in the crust of the globe, crystallization alone would diminish the terrestrial radius at least 1430 metres, and consequently alter the form and rapidity of rotation of the earth. Such speculations are practically useful only in a negative sense, as shewing the great improbability of anything like a shell of 40,000 metres having cooled and consolidated at once in the crust of the earth during any of the known geological epochs.

CHAPTER V.

AQUEOUS ROCKS—MECHANICALLY FORMED.

We are compelled to look upon the igneous rocks as original productions. We can only speculate, and that very vaguely, on what was the condition of their materials previously to their being placed, in a molten state, in the positions where they subsequently consolidated.

In our examination of the aqueous rocks, however, we can go a step farther back, and learn, either accurately or approximately, whence the materials composing them were derived, and what was their previous condition. This is true of all aqueous rocks, whether chemically, organically, or mechanically formed.

We will examine the mechanically formed rocks first.

Preliminary Remarks on the Origin of Mechanically Formed Aqueous Rocks.

The instruments used by nature in the production of these rocks are, moving water, whether fluid or solid (ice), and moving air.

The Sea.—The sea is probably never and nowhere stagnant. Currents, moving with greater or less rapidity, keep the whole mass in circulation ; so that we may look upon the ocean, through all its depths, and in all its gulfs, bays, and recesses, as one great slowly moving whirlpool.*

It is probable, however, that no currents produce any marked or appreciable effects upon solid rock at great depths of water. The mechanical powers of the sea are principally brought into action by the motion of its surface along the shores of all lands, and in its narrower and shallower channels. Sea-breakers along beaches, and at the foot of cliffs, act like ever-moving jaws constantly gnawing at the land. The currents caused by the ebb and flow of the tides along shallow shores remove some of the eroded materials ; the great oceanic currents of

* See Maury's Physical Geography of the Sea, and Johnstone's Physical Atlas, etc. It is of course unlikely that there should be strong currents at great depths, and yet it appears unlikely that any depth should be utterly stagnant, and not affected by any motion, either lateral or vertical.

circulation, where they strike upon coasts, carry off others, and transport all, either mediately or immediately, to greater distances.

Sometimes the breakers, after exerting a certain amount of destructive action, seem to raise a rampart against themselves out of the very ruins they have caused, by the fall of the blocks and masses they have undermined; but the materials thus accumulated are often themselves then attacked, and ultimately removed, and the coast laid bare for new undermining action. Great accumulations of pebble beaches are common along many coasts, and seem to remain stationary, since there are always piles of pebbles to be found in the same places. If, however, these are watched, the accumulations will often be found to consist of different pebbles from day to day, each pebble being in its turn washed from its place, which is occupied by another like it. The great Chesil Bank, connecting the island of Portland with the mainland, and sixteen miles in length, is a remarkable example of such an accumulation of pebbles, the pebbles in any particular part of it being all much of the same size, but each one travelling gradually onwards, and getting smaller and smaller as it proceeds.

Sometimes waves and currents bring and deposit materials on shores, and thus seem to produce rather than to destroy; but those matters have been themselves acquired by the destruction of land at other localities, and are often eventually removed again by a change in the direction of the currents, or other circumstances.

In speaking of the destructive action of water, indeed, we must never forget that by *destruction* we do not mean *annihilation*, but only *re-arrangement.* Rock forming "land," that is, rock above the level of the sea, is destroyed; but its materials are carried off and deposited, either in similar or in different combinations, to form rock below the level of the sea.

Where the range of tide is considerable, some of these materials may be deposited, and form rock between high and low-water mark.

Where the heave of the breakers is great, some of them may be even cast up to a slight distance above high-water mark, and rock may be thus produced.

An interesting instance of the formation of land by the action of the sea may be observed along the coast of Wicklow, between Greystones and Wicklow Harbour. A great bank of pebbles has been thrown up for about eight or nine miles in front of the old shore, and sometimes more than half a mile from it. In some places, especially near Wicklow, a previous sandbank had been formed as that called the Murrough of Wicklow. These banks cut off from the sea a long and narrow salt-water lagoon, to which the sea retained an entrance at the gap between the pebble beach and the hard rocky headland at the town

of Wicklow. The upper part of this salt water lagoon is now converted into a marsh by the confluent deltas of the brooks coming from Newtown Mount Kennedy, the waters of which now run into the sea through the pebble beach. The lower part of the lagoon is in like manner being filled up by the deltas of the Vartry and Rathnew brooks, which will ultimately break through the pebble beach, opposite their present mouths. The quantity of sea-water entering at the mouth of the harbour is annually becoming less, in consequence of the silting up or the upper part of the lagoon; and the mouth of the harbour, which is about two miles below that of the brooks, is therefore more and more choaked with deposits during storms, which the scour during ebb tide is less and less able to remove. The whole of the Broad Lough, as it is called, will therefore be ultimately converted into dry, or at least into marsh land, and the harbour itself obliterated, unless artificial means be adopted to keep it open.

For instances of the erosive and destructive action of the breakers, and the abrading and transporting power of currents, during historic times, we must refer the student to Sir C. Lyell's Principles of Geology, chapters 20, 21.

Along the eastern coasts of Scotland and England, as is proved by old records, land existed far outside the present shore, the sites even of important towns of the twelfth or fifteenth centuries being now under the sea. Even still in many places whole acres are annually consumed, and the total known destruction of the last few centuries is to be measured sometimes even by miles.*

All Sea Cliffs formed by Erosive Action of Sea.—When we have once become aware of the erosive action that is now daily going on, and have learnt to observe its progress and the marks of its action, we are soon irresistibly led to the conclusion that all sea cliffs, crags, and pinnacles of rock have been produced by the erosion and destruction of the formerly more widely extended land; and the height and extent of the cliff, together with the hardness and durability of the rock composing it, will give us a means of estimating the power of this action, and the time consumed in it.

The estimate thus formed will never exceed, but may often fall far short of the truth, inasmuch as the ultimate result of this agency is to bury and conceal from our sight the monuments of its action. We may feel quite sure that the cliff has been formed in consequence of the removal of the rock which once fronted it, or intervened between

* While walking on the cliffs near Barton, in Hampshire, in company with Sir Charles Lyell, in the spring of 1856, as we were looking down upon the shattered slope of fragmentary and broken masses that stretch between their summit and the beach, we were assured by a farmer of the neighbourhood that they commonly reckoned their average loss per annum at a yard of land all along the coast.

it and the former position of the coast,—but we can never feel assured how much land has been thus removed since the present partly destroyed features of the ground may have once been protected by land with different features of its own. Land, moreover, such as any island, may at last be completely worn away and destroyed; all that was once above the level of the sea being carried off and strewed over its bed, leaving to us no visible record of the event.

Inland Cliffs, Precipices, and Mountain-passes formed also by Erosive Action of Sea.—But when we feel ourselves entitled to take for granted that all cliffs at the foot of which the sea is now beating, have been produced by the erosive action of its waves, it only requires us to admit that the land may have stood formerly at lower levels, so as to allow the sea to flow over the lower parts of it, for us to see the probability that all inland cliffs, scars, precipices, valleys, and mountain passes, may have been produced in the same way.

The passes leading across the crests of great mountain chains could have been produced by no other cause than by the eroding action of the tides and currents as the mountains rose through the sea; what are now "passes" having then been "sounds" or straits between islands.

The idea sometimes entertained that these gaps or passes on the crests of mountains have been formed by convulsive fractures and gapings of the surface, produced by disturbing forces proceeding from the interior of the earth, is in all cases an erroneous one. Its mistake can always be shewn by examining the floor of the pass, when the rocks will be seen to stretch across it unbroken by any fracture, and as solid and undisturbed as in any other part of the mountain. Isolated crags and precipices, or long lines of cliff and of steep slopes, looking down upon broad plains, must have in like manner been formed by the sweeping power of the sea. Broad open valleys attest a similar origin, and speaking generally, the principal features in the form of the ground in all lands have been produced by this wide-spread action.

The removal of vast masses of rock, therefore, by this agency, and its transport to the beds of neighbouring seas and oceans becomes certain. The results of this erosive action are exhibited to us often in the most striking manner in the gorges and ravines of mountain slopes, but low gently undulating grounds frequently present examples of it that are in reality still more wonderful; since geologists can prove that such grounds were once covered by great mountains, or at least by masses of rock which were equal in bulk to the greatest of existing mountains, and that these vast masses have been ground down and utterly removed and swept away, so that we have now left merely the base on which they stood.

To such agency we can only allude here in brief and general terms,

so as to prepare the student to estimate rightly the forces and the actions which we shall have to consider in their proper place.

Rain.—The sea, however, is not the sole agent of the destruction of that portion of rock at or above its level, which we call land. All rain falling upon land, and either running over its surface or draining through its interior, is constantly abrading and carrying off particles of pre-existing rock in the shape of mud, silt, and sand. From the gutters and the ditches, from the rills, the streams, and the brooks, these materials for the building of mechanically formed rocks are almost unceasingly being carried into the rivers, and by them transported to the beds of lakes and seas. Insignificant as such an action may appear to us, its results when continued through hundreds and thousands of years become far greater than we should at first imagine.

Landslips.—Rain soaking into ground, and issuing as springs on steep slopes or precipices, sometimes exerts a more wholesale destructive power, by gradually loosening and undermining very considerable masses of ground, and thus causing them to be *launched* forward, down the slope, producing what are called "landslips." Examples of landslips are common in most hilly countries. Some of them are described by Lyell in the twentieth chapter of his Principles, especially the remarkable one (originally described by Buckland and Conybeare), on the coast of Dorset, when a mass of chalk slid over the surface of a bed of clay down into the sea, leaving a rent three-fourths of a mile long, 150 feet deep, and 240 feet wide, the whole mass on the seaward side of it, with its houses, roads, and fields, being cracked, broken, and tilted in various directions, and thus prepared for being more easily carried off by the action of the sea.

Far larger instances of ancient landslips, of which no record is known, and which took place perhaps before historic times, or even before the country was inhabited by man, may be observed in some parts of the south-west coast of Ireland. On the coast west of Bearhaven in county Cork, and west of Brandon Head in county Kerry, as also in Derrymore Glen between the mountains called Baurtregaum and Cahirconrea, great cliffs were observed during the progress of the geological survey, in which the beds of rock lay, in most abnormal and puzzling positions, so that it was difficult to understand how they had assumed them, until the idea struck me that they formed parts of gigantic landslips, an idea which, when once suggested, readily accounted for the circumstances. Masses of land with cliffs 800 feet high were then seen to be nothing but a confused heap of broken ruins, their cracks and dislocations being superficial only, or not extending below the level of the sea.

Ice and Snow.—When rain falls as snow, on the other hand, it

exerts a conservative and protective effect as long as it retains its solid form, but, on melting, acts like rain, and even with greater intensity, inasmuch as a greater amount of water is often set loose and in motion over the land by the rapid melting of snow than would fall in the same space of time in the shape of rain directly from the clouds. The most extensive and powerful floods are those of the spring in mountainous districts, when the snows melt rapidly on the hills.

If rain or other water soaks into rocks and fills up their interstices, either the small pores, or the crevices, joints, and fissures, by which all rocks are traversed, and this water then freezes, its conversion into ice is accompanied by an expansion which exercises an irresistible mechanical force, the effect of which will be either the disintegration of the particles in the one case, or the breaking and rending asunder, and the displacement of the larger masses in the other. On mountain summits and sides, subject to great vicissitudes of temperature, this agency exerts no mean effect. The hardest rocks may be broken up by it, and enormous blocks ultimately displaced and toppled over precipices, or set rolling down slopes to suffer still further fracture, and produce still greater ruin in their fall.

Few men live in situations enabling them to observe, and of those still fewer have the ability or the inclination to note and record the amount of this agency in the remote and inaccessible places where it is greatest. Its amount, however, may be measured by the piles of angular fragments, large and small, lying at the foot of crags and precipices, or sometimes on the sharp peaks and steep summits of the mountains, where they are the ruins of formerly existing "torrs" and pinnacles.

Captain Beechey in his voyage towards the North Pole (Dorothea and Trent), describes the amount of this action as very great in Spitzbergen. He says that the mountains were rapidly disintegrating from the great absorption of wet during summer, and its dilatation by frost in winter. "Masses of rock were, in consequence, repeatedly detached from the hills, accompanied by a loud report, and falling from a great height, were shattered to fragments at the base of the mountain, there to undergo a more active disintegration." Soil was thus formed, he says, up to 1500 feet above the sea. (See Sir J. Richardson's Polar Voyages, p. 207).

Glaciers.—When mountains are covered by perpetual snow, all the parts so covered are protected by this envelope from all change. In such situations, however, the moving power of water takes another form, that of the glacier, or "river of ice." The lower border of the perpetual snow-mass passes into ice, partly from the pressure of the mass above, and partly from the alternation of melting and freezing temperatures, just as snow on the roof of a house forms icicles at its

lower edge, when some of it is melted by the sun or the warmth of the house, and refrozen by the cold from evaporation, or the next night's frost. This ice accumulates in the valleys, and is frozen into a solid or nearly solid mass, called a glacier. Glaciers sometimes fill up valleys twenty miles long, by three or four wide, to the depth of 600 feet. Although apparently solid and stationary, they really move slowly down the valleys, and carry with them, either on the surface, frozen into their mass, or grinding and rubbing along the bottom, all the fragments, large and small, from blocks many tons in weight, down to the finest sand and mud, that rain, and ice, and the friction of the moving glacier itself, detach from the adjacent rocks.*

The glaciers of the Alps, and probably those of other parts of the world, descend to a vertical depth of nearly 4000 feet below the line of perpetual snow, before they finally melt away, and leap forth as rivers of running water. The confused pile of materials, of all sorts and sizes, which they there deposit, is called the "moraine." This word is also applied to the lines of blocks that are carried along on the surface of the glacier, which are called the lateral moraines, the one at the end of the glacier being styled the terminal moraine.

It is easy to understand that a glacier slipping down its valley, may bear on its sides the blocks and fragments that fall from the adjacent cliffs, just as a river would carry down the stems and sticks and leaves from the woods on its banks. A line of these might in each case be seen on each side of the stream, and if two streams unite, the two lines of transported substances on their adjacent sides would likewise unite, and be carried down as a double medial line along the centre of the stream below the junction. In this manner, if a glacier have many tributaries in its upper parts, the lower portion of it may have many medial lines of moraine, and in some cases so many as to be entirely covered with a confused stratum of debris.

The river of water that always springs from the end of a glacier, is of course quite unable to move the larger blocks which have been carried down by the glacier, and they remain in the terminal moraine until they are worn away, or broken up by atmospheric influences. The river, however, carries off at once the fine mud and impalpable sand and powder† derived from the grinding action of the glacier, and

* For the description of the glaciers of the Alps, and the cause of the motion of glaciers, see the works of Agazziz and Charpentier, J. Forbes, and Dr. Tyndall; for those of the Himalaya, Dr. Hooker's Himalayan Journals.

† The ice of a glacier seems in its lower part to be always full of little bubbles, containing small nests of this dirty powder. I observed in the summer of 1860, that at some of the hotels in Switzerland (especially at Chamounix, at the Hotel des Londres), ice was provided at the table d'hôte. This was of course glacier-ice, and on putting a piece of it into a glass of water, first one and then another of the little bubbles in the ice burst, as its walls

flows as a dirty yellowish or greenish white stream of filthy water, until it reaches the sea, or some great lake like that of Geneva, in which the sediment may be deposited. The Rhone that has become purified in the Lake of Geneva, is, shortly after issuing from it, contaminated by the Arve and other rivers below. The Rhine after leaving Lake Constance, in like manner receives the Aar with all the washing of the glaciers of the Oberland, and rolls henceforth a rapid turbid stream into the German Ocean. Holland is in great part composed of mud from the glaciers of Switzerland.

Icebergs.—If, however, it so happen that a glacier come down into a lake, or into the sea, before it melt away, large fragments of it (icebergs) will be frequently floated off, with all their freight of rock-fragments of all kinds; and these loaded icebergs may then be carried great distances before they entirely dissolve. In this manner, large unworn angular blocks of rock may sometimes be dropped on the bed of the sea even hundreds of miles from their original site. The terminal moraine, instead of a pile at the foot of the glacier, is thus disseminated far and wide over the bottom of the surrounding seas.

The finer sediment imparted to the sea by melting icebergs may, of course, be carried still further by the oceanic currents, and thus mud at the bottom of a tropical ocean may be derived from the grinding of arctic or antarctic land.

River Valleys.—Rivers form their own beds, but not their own valleys. Rivers are the results of their valleys, but they are their immediate results. The river could not be formed till after the valley, with all its tributary branches, had been marked out; but the valley could not even be marked out without the river, in most cases, simultaneously springing into existence, and commencing to form its channel or bed, and thus modify, and deepen, and complete the valley.

If we watch the tide receding from a flat muddy coast, we see that the mud flat, even where no fresh water drains over it from the land, is frequently traversed by a number of little branching systems of channels, opening one into the other, and tending to one general embouchure on the margin of the mud flat, at low-water mark. The surface of the mud is not a geometrical plane, but slightly undulating; and the sea, as it recedes, carries off some of the lighter and looser surface-matter from some parts, thus making additional hollows, and forming and giving direction to currents, which acquire more and more force, and are drawn into narrower limits, as the water falls. Deeper channels are thus eroded, and canals supplied for the drainage of the

melted, and a cloud of sediment was discharged into the water, so that in the space of ten minutes, the glass of water which was at first quite clear, became as turbid as if a spoonful of milk had been dropped into it.

whole surface. First two, and then more, of these little systems of drainage unite, until at dead low-water we often have the miniature representation of the river system of a great continent (wanting of course the mountain chains), produced before our eyes in the course of a single tide, in the very manner and by the very agent by which all river systems on all islands and continents have been produced.

The difference between them is this only, that our islands and continents are now above the sea, not in consequence of the gradual fall of the water, but in consequence of the gradual rise of the land.

It may be said, moreover, that this little drainage system thus set up in a mud flat is not the result of the action of one tide, that it is not obliterated every time it is covered at high-water, and reproduced again afresh, but is the final result of many elevations and depressions, and many successions of drainage action, all combining to produce the same effect in the same lines, wherever nothing has happened, in the meanwhile, to direct them into different ones.

Just so, however, it is with the river systems of our dry lands. The present form and contour of our lands, and their partition into basins of drainage or river systems, each divided from the other by lines of "watershed," is the result of many elevations above the sea, and depressions below its level. The internal forces of elevation and depression have acted not once only, but many times; and accordingly the whole surface of our land has been, *not once only, but often*, subjected to the graving tools and gouges, the planes and chisels, so to speak, of the upper surface of the sea; the hollows and excavations thus caused not having been obliterated, but generally deepened and intensified on each occasion.

Action of Rivers.—This re-direction of draining water into old channels will be more certain and frequent in proportion to the steepness of the ground and consequent rapidity of the flow of water; and channels once selected will there be more rapidly deepened, and more completely and permanently formed. Such deep valleys (ravines, as we should then call them) are scarcely to be obliterated, or otherwise altered than from deepening and enlargement, by any number or amount of changes, short of the removal of the mass of high ground which they traverse. As long as the mountains remain undestroyed, the valleys and ravines must obviously be continually enlarged, either vertically or laterally, by the action of the waters which traverse them.

The erosive action of mountain torrents can hardly fail to be perceived by any one who visits them. In their narrow channels, smooth grooves and cuts, obviously water-worn, may often be observed, even in the hardest rocks; while holes, called "pot-holes," of several feet in depth and width are often formed in such rock by the whirling action

of water keeping in perpetual circular motion a few pebbles or a little sand. Cascades and waterfalls dig deep holes and black pools below the ledges over which they fall, and often undermine those ledges, and thus break them away, block by block, much faster than the abrasion of mere water friction could remove them. Cataracts cut their way back in all rivers, whether in the ravines of mountains, or when they fall from one plain or one table-land to another, as in the case of the Falls of Niagara and others. The ravine that the river St. Lawrence has excavated for itself by the recession of its Falls is 7 miles long, 200 to 400 yards wide, and 200 to 300 feet deep, and would require something like 35,000 years for its production, at the present rate of progress.—(*Lyell's Principles of Geology*, chap. xiv.)

The amount of sediment transported by a river at any given time varies very greatly, and the amount transported by different rivers is also very various. Dr. Livingstone (in his Missionary Travels in South Africa, p. 598), describes rivers which ordinarily have more sand in them than water. He says, "We came to the Zingesi, a sand rivulet in flood. It was sixty or seventy yards wide, and waist deep. Like all these sand rivers, it is for the most part dry; but by digging down a few feet, water is to be found, which is percolating along the bed on a stratum of clay. . . . In trying to ford this, I felt thousands of particles of coarse sand striking my legs. . . . These sand rivers remove vast masses of disintegrated rock before it is fine enough to form soil. . . . The shower of particles and gravel which struck against my legs gave me the idea that the amount of matter removed by every freshet must be very great. In most rivers where much wearing is going on, a person diving to the bottom may hear literally thousands of stones knocking against each other. This attrition being carried on for hundreds of miles in different rivers, must have an effect greater than if all the pestles and mortars and mills of the world were grinding and wearing away the rocks."

The temporary damming up of rivers, and subsequent breaking down of the barrier and escape of the lake formed above it, produces sometimes the most remarkable instances of the power of moving water. Rocks as big as houses are thus set in motion and carried sometimes for very considerable distances down the valleys.—(See *Lyell*, as above; also *Jameson's Mineralogy*, vol. iii., and *De la Beche's Manual and Geological Observer*.)

The blocks accumulated in mountain torrents are usually crags that have been gradually loosened by the weathering action of the spray, or undermined by the abrasion of the water, and then fallen into the bed of the river. These blocks, arresting the force of the stream, are immediately attacked by it, and very soon become smooth and rounded by

attrition, either of the mere water, or of water charged with sand and gravel. When sufficiently lightened, and sufficiently rounded and polished, some greater flood than usual sets them in motion, to receive still further rough treatment themselves, and to become converted into tools for the breaking up and grinding of others, till at length the massive and shapeless crag is rolled forward into the brook in the form of a quantity of small round pebbles. These undergo here a continuation of the same mechanical operation as before, till they are delivered by the brook into the river in the shape of grains of sand, and are thus swept onward towards the sea; and if the river be very large, long before they reach the sea the sand is ground down into mud of the finest and most impalpable description.* Clouds of such mud discolour the sea off the mouths of great rivers, such as the Amazon and Orinoco, even for many scores of miles out of sight of land;† and the great ocean currents may carry it on, still slowly sinking through greater depths, even for many hundred miles further, before it finally settles to rest in some tranquil hollow of the bed of the ocean.

Difference between River Action and that of Sea.—Although the sea and the river both cut away and carry off rock by the power of moving water, the result of their action is easily to be distinguished. The sea acts for the most part along a horizontal plane, cutting down land to its own level with a broad, widely-spread action, always tending to produce a level surface, not only over the land which it destroys, but by filling up the hollows in its own bed with the materials derived from that land. The river, on the other hand, acts in a vertical direction, cutting its way down over a comparatively narrow and often tortuous line of ground, and thus tending to make the surface rugged and uneven, and to wear in it deeper and deeper valleys or ravines. We shall have occasion hereafter, when speaking of "Denudation," to remark this difference in the effect produced upon the surface of land more particularly.

Motive Powers of Water.—We shall be able better to understand how rapidly the size of water-borne fragments increases in proportion to the velocity of the moving water, when we learn from Mr. W. Hopkins,‡

* For a description of these facts as observed in the bed of the Ganges and its tributaries, see Hooker's admirable Himalayan Journals, vol. i., p. 378.

† "The river Plata, at a distance of 600 miles from the mouth of the river, was found to maintain a rate of a mile an hour; and the Amazon, at 300 miles from the entrance, was found running nearly three miles per hour, its original direction being but little altered, and the water nearly fresh."—(*Admiralty Manual of Scientific Inquiry*, note, p. 24.) Nothing is said there of the sediment in the river, but I have myself seen, when anchored ten or fifteen miles from the shore of New Guinea, north of Torres Straits, the waters of the much smaller rivers of that island rush out as the tide fell, with a strong discoloured stream of some miles in width, and in such quantity as to be shortly drinkable alongside.—(*Voyage of the Fly*, vol. i., pp. 217 and 219.)

‡ See Presidential Address to the Geol. Soc. Lon., for year 1852, p. xxvii.

that the power of water to move bodies that are in it increases as the sixth power of the velocity of the current. Thus if we *double* the velocity of a current, its motive power is increased *sixty-four times;* if its velocity be multiplied by 3, its motive power will be increased 729 times; if by 4, 4096 times; and so on.

In studying the mechanical force of water upon rock, also, it is necessary to bear in mind that all earths and stones lose fully a third of their weight when suspended in water. These considerations enable us to understand more readily the fact of blocks of rock many tons in weight having been removed from breakwaters and jetties, and carried sometimes many yards during great storms, as also of still larger blocks hurried along by floods, etc.

The rolling power of water upon stones lying in its bed depends greatly on their shape also, the same current being easily able to roll along pieces of rock in the form of rounded pebbles, that it would be quite unable to move if they were in the shape of flat slabs; while, conversely, flat slabs or flakes would float more easily, or sink more slowly, than rounded or square-shaped fragments of the same weight and cubic contents. Flakes of mica, as Sir C. Lyell observes, therefore, might be floated and transported onwards where grains of quartz, even though lighter than the mica, would sink; and, on the other hand, rounded quartz pebbles might be rolled forward where smaller and flatter pieces, in the shape of shingle, would be brought to rest.

Mr. Babbage has lately treated of this subject, in a paper of which an abstract appeared in the Journal of the Geological Society, November 1856.

He there supposes the case of a river, the mouth of which is 100 feet deep, delivering four varieties of fine detritus into a sea which has a uniform depth of 1000 feet over a great extent, which sea is traversed by one of the great ocean currents, moving with a certain given velocity.*

He takes for granted that the four varieties of detritus are such as, from their size, shape, and specific gravity, would fall through still water, the first 10 feet per hour, the second 8 feet, the third 5 feet, and the fourth 4 feet. The combined effect of the downward motion of the detritus and the onward motion of the water, would then bring the first variety to the bottom of the sea, at a distance of 180 miles from the river's mouth, and strew it over a space 20 miles long; the second variety would only begin to reach the bottom 225 miles from the river's mouth, and would be spread over 25 miles, and so on, as in the following Table:—

* The supposed velocity of the river and ocean current is not stated in the abstract, but from the calculation would appear to have been taken at 2 miles per hour.

No.	Velocity of fall per hour.	Nearest distance of deposit to river mouth.	Length of deposit.	Greatest distance of deposit from river mouth.
	Feet.	Miles.	Miles.	Miles.
1	10	180	20	200
2	8	225	25	250
3	5	360	40	400
4	4	450	50	500

We should thus have, proceeding from the same river, and poured into the sea either simultaneously or at different times, four different and widely separated patches of mud or clay formed on the sea bottom.

Mr. Babbage says, that this subject was suggested to him from his observing the *extreme slowness* with which a very fine powder, even of a very heavy substance, such as emery, subsides in water, and he speaks of mud clouds being suspended in the depths of the ocean, where the density of the water increases, for vast periods of time.

Amount of Matter transported by Rivers.—The amount of mechanical work done by rivers can be estimated by examining their waters at different periods, and determining their solid contents. If this be done by simply evaporating the matter, the result will be not only the mechanically suspended mineral matter, but also that which was chemically dissolved in the water. As the separation of these two, however, is rather troublesome, and not very important, it is not often attempted; neither, as a measure of the work done, would it be often necessary, since the chemical solution of mineral matter is perhaps more frequently than not the consequence of the mechanical erosion of it by the water.

Sir C. Lyell, in his *Principles*, gives the following as the results of various observations:—

The total mineral matter carried down by the Ganges into the sea, according to Everest, is 6,368,077,440 cubic feet per annum. Lyell says, that for the transport of this quantity, it would require a fleet of 2000 Indiamen, each of 1400 tons, to start every day throughout the year. Such a mass of matter would cover a square space 15 miles in the side every year with mud a foot deep, or would raise the whole surface of Ireland one foot in the space of 144 years. The Brahmapootra probably carries an equal quantity.

Mr. Barrow calculated that the Yellow River (Hoang Ho) in China, carried down into the Yellow Sea 48,000,000 of cubic feet of earth *daily*, so that, assuming the Yellow Sea to be 120 feet deep, an English square mile might be converted into dry land every seventy days,

and supposing its area to be 125,000 square miles, the whole would be made into terra firma in 24,000 years. According to Dr. Riddell, the solid matter contained in the Mississippi is about 80 parts in the 100,000 of water by weight, or about 33 by volume ; and Sir C. Lyell calculates that it brings down 3,702,758,400 cubic feet annually, and that the present delta has required 67,000 years for its formation.

If we turn to the European rivers, Bischof, in his Chemical and Physical Geology (vol. i., chapter 81) states that Chandellon, by daily experiments during December 1849, found in the Maes, at Liege, a maximum of 47.4 parts of suspended matter alone, a minimum of 1.4, and a mean of 10 parts, in the 100,000 of water.

In the Rhine, at Bonn, Mr. Leonard Horner found, August 1833, when it was unusually low and turbid, 31.02 of suspended and dissolved matter, and in November, when swollen, 51.45. Bischof found in March 1851, 20.5 of suspended matter alone, and at another time, when it was clear, only 1.73 of such parts ; while Stiefensand, near Uerdingen, after a flood, found 78 parts of suspended matter in the 100,000 of water.

In the Danube, August 5, 1852, there were found 9.23 of suspended, and 14.14 of dissolved matter, total solids 23.37 in the 100.000; while in the Elbe at Hamburgh, there were in June 1852 only found 0.9 of suspended, and 12.7 of dissolved matter.

In these experiments much depends on the state of the river, and also on the part of the river where the water is taken from, whether far from the bank, at the surface, or near the bottom, and so on.

Formation of Deltas.—We may also in many cases estimate the amount of work done by a river, from the size of the delta or flat land formed at its mouth. If we follow the course of any river from its source to its termination, we perceive that the size of the river and the volume of water it contains is continually increased by the accession of tributary streams now on one side and now another. No stream ever flows out of a river, nor does the river ever divide into two streams, except for a short distance where a comparatively small island may have been formed in some flat part of its bed. When, however, we follow a river down to a low flat country on its approach to a lake, or to a part of the sea at the head of a bay or gulf, or where no oceanic currents sweep across its mouth, or where from any circumstances the sediment brought down is more than can be carried away into deep water, we then find the river split up into two or more branches by the formation of a delta.

In the delta part of a river an entire change takes place in its nature ; instead of continually receiving fresh accessions of water, and so becoming larger and larger ; the river now splits into smaller and smaller channels. In the upper parts, fresh accessions of earthy mat-

ter are brought into it, but now it begins to deposit the sediment it contains.

In fact, the river properly ceases at the head of the delta, where its mouth originally was, and its water merely finds its way out into the lake or sea below in the best fashion it can through the mud with which it has choaked its own mouth.

The Rhine when it enters Holland is in fact lost in a great deltoid flat among a number of bifurcating channels, in which its waters are mingled with those of the Meuse, the Sambre, and a number of other rivers, such as the Scheldt, which have all contributed to produce the low marshy ground that skirts the coasts of Belgium, and forms nearly the whole of the Netherlands.

So obviously is the delta of the Nile the production of that river, that Herodotus remarked that "Egypt was the gift of the Nile," and that the sea probably once flowed up to Memphis, now more than 100 miles from the coast-line, the old gulf having been filled up by the Nile mud as the Red Sea would be filled up if the Nile were turned into it. The edge of the present delta, which is 150 miles wide, is, however, now swept by a powerful current, which carries off all detritus delivered into it, and thus future increase is prevented. Otherwise the Nile would by this time have formed a long tongue of land projecting into the Mediterranean, just as the Mississippi has projected a tongue of land 50 or 60 miles long into the Gulf of Mexico, having previously filled up the inlet which formerly penetrated from that sea deeply into North America, and received the rivers more than 100 miles inland from the present coast.—(*Lyell's Principles.*)

The Ganges first bifurcates at a distance of 220 miles from the present coast, and the river may be said, like the Rhine on entering Holland, properly to terminate there, for below that it splits into numerous channels among marshy ground, which it has formed in conjunction with the Brahmapootra and other rivers. This muddy flat stretches for 260 miles along the head of the Bay of Bengal.

Dr. Hooker in his description of this district (Him. Journals, vol. ii., p. 341), says, speaking of its eastern border, "The mainland of Noacolly is gradually extending seawards, and has advanced four miles within twenty-three years; this seems sufficiently accounted for by the recession of the Megna" (a name for the main branch of the Brahmapootra). "The elevation of the surface of the land is caused by the overwhelming tides and north-west hurricanes in May and October; these extend thirty miles north and south of Chittagong, and carry the waters of the Megna and Fenny back over the land in a series of tremendous waves that cover islands of many hundred acres, and roll three miles into the mainland. On these occasions the average earthy deposit of silt sepa-

rated by micaceous sand is an eighth of a mile for every tide, but in October 1848 these tides covered Sundeep island, deposited six inches on its level surface, and filled up with mud ditches several feet deep."

The bifurcations of the Brahmapootra commence even further from the sea than those of the Ganges, and there is a great flat of more than 100 miles in width between the two, in which a number of lesser streams proceeding directly from the southern slopes of the Himalayas likewise bifurcate, some of them beginning to do so at 300 miles from the sea-coast. It would appear, therefore, that we have here a vast river-deltoid deposit, covering an area of something like 50 or 60,000 square miles, or more than that of England and Wales.

Sir C. Lyell (*Principles*, chapter 19) tells us that an Artesian well, 481 feet deep, was bored at Calcutta, of which the upper 400 feet at least may be stated as river deposit, although giving evidence at one or two places of the land having formerly been at a higher level, and the river therefore having brought coarser materials than now.

Large and thick as this great mass of mere river washing may appear, it does not represent the whole quantity brought down, since we learn from Lyell that outside the part which may be called actually land, there is a gradual slope out to sea of more than 100 miles—the water slowly and regularly deepening from 4 to 60 fathoms. In the centre of this submarine slope, too, is a deep hole about 15 miles across, called "the swatch of no ground," in which no bottom is found with 100, or even 130 fathoms of line, giving us apparently a measure of the depth the water would have had over the whole neighbouring space if it had not been for the mud brought down by the river.

The great rivers, however, which do not block up their own mouths with a delta, do not the less on that account carry down sediment into the sea. The Rio Plata and the Amazon have their mouths probably swept clean, partly by the force of their own current carrying out the detritus into deep water, and partly by the oceanic currents which travel past their mouths aiding them in this transport. The river St. Lawrence is greatly strained of sediment by having to pass through the large lakes which it must first fill up and convert into dry land before it can begin to form a delta at its mouth.

The Thames and Severn, and other smaller rivers of our own islands and other parts of the world, fall into the tidal waters with too short and too rapid a slope to commence the formation of a regular delta, the falling tide helping the river flow to scour out the embouchures, although many large sandbanks are deposited about the mouths of such rivers, the materials of which have been brought down by them.

The set of the currents in the German Ocean seems to be directed from the Continental and against the English shores; but where any

part of the latter is protected from the sweep of those currents, as in the deep bight called the Wash between Norfolk and Lincolnshire, there the rivers make a deltoid flat or great marsh, scarcely above the level of the sea. Such are "the fens" of Cambridge and Lincoln, a tract of about 2000 square miles, the product of the rivers Witham, Welland, Nen, Ouse, Cam, and others.

In the tropics these fens would have a huge mangrove swamp along their seaward edge, while inside that there would be a jungle like the Sunderbunds of the Gangetic delta.

Transport of Matter by the Ocean.—The same reasoning just now applied to the place of deposit of the earthy materials derived from rivers is equally applicable to the mud and sand washed from all coasts by the erosive action of the breakers, which may be carried out by tides and currents far from the land, wherever the materials are fine enough to be held long in suspension, and the currents swift enough to move far in that time.

The current that sweeps round the extremity of Africa from the Indian Ocean to the Atlantic, is at once distinguishable by its dirty olive green colour from the deep blue of the pure ocean water, even in a depth of 100 fathoms, and out of sight of land. Small pebbles were brought up from that depth by the lead in H.M.S. Fly; and the change of colour in the water can hardly be due to any other source than the presence of minutely divided mineral matter held in suspension by the water.

Among coral reefs, where there is no mechanically suspended matter in the water, it is of crystalline clearness, and deep blue colour, even in such small depths as fifteen and twenty fathoms, and it is only on shoals of less than ten fathoms where the white or yellow bottom begins to appear through the water, that a green tint appears which becomes plainly visible, even at a distance of one or two miles, when the water shoals to four or five fathoms. This, however, is a bright grass green, very different from the dull green of the Agulhas current and our own and other shallow seas.

Similar differences in the colour of the sea, arising from the same cause, may be seen on our own coasts. The sea on the west coasts of Ireland and Scotland, where the current sets upon the land from the gulf stream, is the deep clear ocean blue, even in the bays and harbours, and is very different from the dirty green water of the English Channel, the Irish Sea, or the German Ocean, which has become loaded with matter from the washing of our coasts and rivers. This difference may be seen on the small scale in the bays of the western coasts. I have often been struck with the appearance of Bantry Bay after a day's storm and rain, when a margin of green discoloured water may be seen

extending some half mile in width all round the shores, singularly contrasted with the bright blue water of the bay. In dry calm weather, there is no discoloured margin ; and the general blueness of the water is not affected by the bottom, which inclines very gradually and regularly from five or six fathoms at the head of the bay, to about twenty-five at its mouth, and consists of a fine-grained silt, principally composed of broken corallines and shells.

I had occasion once to cross Kenmare Bay between Collorus and Sneem the day after a tremendous storm, when these appearances were singularly well marked. In the centre and lower part of this long and beautiful inlet the water was still blue and clear, but all round its head and along its sides the colour of the water was greenish yellow. The boundary between the two kinds of water was perfectly well defined, so that it could be seen from a boat a quarter of a mile ahead, and the moment observed in which the boat passed from one kind of water to the other. The dirty water appeared to be slowly travelling down with the receding tide toward the mouth of the inlet.

This discolouration of the water, then, is due to nothing else than the washing of the land during heavy rains and storms, proceeding either directly from the cliffs or from the numberless little brooks and rivers, and must exist under the same circumstances round all lands. No small amount of earthy matter is thus annually conveyed into the sea, swept off by its currents, and deposited somewhere in its bed.

The natural colour of perfectly clear pure water seems, as observed by Professor James Forbes, to be blue. All green water, or water of any other colour than blue, however clear it may look in a glass, nevertheless contains impurities.

The materials derived from the land, either by river or sea action, are carried to greater or less distances according to their fineness. In the Irish sea, according to the Admiralty charts, sand alone is to be found within some miles of the shore, while, in the central and deeper parts, the bottom is formed of mud. There are two central mud-belts in the northern part, one on each side of the Isle of Man, the one running towards the Solway, and the other continuing into the Clyde mouth.

In the English Channel there is nothing to be found but sand, with or without gravel or stones ; but opposite to the entrance of the Bristol Channel, and in the deeper water south of Ireland and west of the Scilly Islands, there are large deposits of mud surrounded by sand, the mud continued in narrow arms, which stretch out into the Atlantic, where it apparently blends with oaze that may probably be of organic origin. In the German Ocean, in like manner, mud is found only in the central and deeper parts, between Denmark and the Dogger Bank,

and in the mouth of the Baltic, between Denmark and Norway, all the seas within some miles of the shore having a sandy bottom.

Off the west coast of Ireland there are some tracts of bare rock, some of sand, and some of mud, at the bottom of the sea. Some of the charts which I have recently coloured according to the nature of the bottom, are highly instructive, as shewing the way in which these mechanically derived materials are deposited in our present seas.

Results.—It results from even such a hasty and rapid glance as we have just thrown over the principal mechanical powers of moving water that are daily and hourly at work around us, that we begin to acquire the notion that we are living in a vast workshop, and that all the earthy matters we see about us, the mud, the clay, the soil, the dust, the sand, the gravel, and the boulders, are only so much raw material in process of manipulation. They may be likened to the refuse and the chips of some vast manufactory. They are the building materials of stratified rocks, which are being carried from the quarry to the place of construction, much being dropped and scattered by the way. Every pebble, every grain of sand, every atom of mud, is a fragment of a pre-existing rock, removed at some period of past time, and destined ultimately to enter into the structure of some other rock in the future.

This building metaphor might be carried still farther when we come to speak of the chemically formed rocks, since many of the mechanical deposits are bound together by cements and mortars which are more or less identical in composition with those used in architecture.

Description of Mechanically-Formed Rocks.

51. *Conglomerate, Puddingstone, Breccia.*—In the preceding pages, we have mentioned the method of formation of pebbles, gravel, and shingle, in rivers and along sea-coasts. When those materials are compacted together into stone, they are called *conglomerate* or *puddingstone* if the pebbles are round, *breccia* if the fragments are sharp and angular.

The pebbles may consist of any substance whatever; but they are most commonly composed either of quartz, quartz rock, or some very siliceous mineral. This is partly the result of the greater abundance of siliceous over other mineral matters in the composition of rock generally; but it also arises from the greater durability of quartzose substances, and from their mode of fracture. Pure silica, or highly siliceous minerals, are not so easily dissolved by water, or by any other commonly occurring solvent, as those which contain lime or other earths and alkalies. On the other hand, quartz and quartz rock, and similar substances,

though very hard, are often rather brittle; and they break into squarish or cubical lumps, rather than into plates or slabs. These squarish lumps are soon converted by motion in water, and the consequent rounding of their angles, into more or less globular pebbles, and are therefore set in motion with comparative facility.

Hence it results that, by "conglomerate" alone we usually understand a mass of quartz pebbles bedded in quartzose sand, and that when the pebbles consist of limestone or of trap, of slate, schist, or other rock, the rock is spoken of as calcareous or trappean conglomerate, etc.

The degree of induration or consolidation in conglomerates varies greatly. Some seem to have been consolidated by simple pressure; and from these the pebbles may often be removed by a slight blow with the hammer, or even by the knife, the form or mould of the pebble remaining in the little film of sand which fills up all the interstices between the larger fragments. Sometimes the conglomerate has been bound or cemented together by calcareous, ferruginous, or siliceous infiltrations, the matrix in which the pebbles lie being as hard and indestructible as the pebbles themselves, a blow with a hammer breaking the pebbles as easily as the mass of the rock in which they are embedded.

The size of the fragments in conglomerates and breccias varies greatly. In some rarer cases, blocks of as much as two feet in diameter occur; but the more ordinary sizes are from that of a man's head to that of walnuts. Below that size, the rock begins to pass into the coarser varieties of sandstone.

52. *Sandstone and Gritstone.*—The remarks as to the usually quartzose character of conglomerates hold good also with respect to sandstones. The very process by which fragments of rock are rounded produces sand, as the waste resulting from their attrition. Pebbles themselves also are gradually broken or diminished into grains of sand.

Sandstone is nothing else but sand, compacted into solid stone. The grains, both of sand and sandstone, generally consist of quartz, sometimes clear and colourless, sometimes dull white, sometimes yellow, brown, red, or green. The red colours are usually the result of the covering of each little grain with peroxide of iron, which sometimes acts as a cement to the stone, serving to bind the particles together. The green colours are commonly derived from silicate of iron; and the green and red are often intermingled, in consequence of the change of the iron from the condition of a silicate to that of a peroxide.

The size of the grains varies from that of a pea to the minutest particle visible to the naked eye, many sandstones and gritstones even requiring a lens in order to distinguish the particles of which they are composed.

The materials are also various, as, along with grains of quartz, may occur grains and particles of any mineral substance whatever.

Feldspathic Sandstone.—Grains of feldspar, distinguishable by their dull white colour and peculiar appearance, occur abundantly in some sandstones, which may then be called *feldspathic sandstones.*

Micaceous Sandstone.—Flakes and spangles of mica are rarely altogether absent; and in many sandstones they occur so abundantly, and in such regular seams, as to cause the rock surfaces to glitter, and the rock itself often to split into thin plates and slabs. These are called *micaceous sandstones.*

Calcareous Sandstone.—When grains of limestone occur in any remarkable proportion, the rock may be called a *calcareous sandstone,* though this designation is often applied to sandstones the quartzose or other grains of which are bound together by a cement of carbonate of lime, either invisible to the eye or occurring as a network of little veins and strings of crystalline carbonate of lime running throughout the stone.

Calcareous sandstones are often called *cornstones,* and the amount of calcareous matter is sometimes so great as to cause them to pass into actual limestone.

The weathered surface of a cornstone or calcareous sandstone is often curiously rotten and soft, and of a dark brown colour, the disintegration of the rock being due to the solution and removal of the carbonate of lime, and its dark colour to the peroxidation of the iron contained in it.

Argillaceous Sandstone is a term not often used, nor is it very often applicable, though many rocks contain various mixtures of sand and clay. In some sandstones, little flat rounded patches of clay, more or less indurated, occur. Similar little patches of clay may be seen on sandy shores, either originally deposited there in little hollows, or rolled as clay pebbles from some bed of clay. In quarrying sandstone, these clay patches are commonly called "galls" by the workmen. In highly indurated grits, they sometimes assume the form of pebbles of *slate,* though the slaty appearance may often have been acquired from the subsequent induration, and not before they were embedded in the sandstone. These patches of clay or apparent fragments of slate, sometimes give to the rock the appearance of a breccia, composed of pieces of hard slaty rocks embedded in sandstone.

Pseudo-crystalline Sandstone.—Among sandstones derived from hard crystalline igneous rocks, it may sometimes not be easy, at first sight, to distinguish between the sandstones and the rocks from which they are derived. If the crystals of the one, after being disintegrated, become compacted together again before their angles are much worn, and retain

undiminished the lustre of some of their facets, and the sandstone or gritstone thus composed be very hard and intractable, pieces of it might easily pass for an actual igneous rock. In most cases, however, the particles of the trap rock are much decomposed before they enter into the composition of the sandstones; and the only mistake that could then be made between them would result from a hasty glance at the weathered surfaces of the two.

Trappean Sandstones, or *volcanic Grits*, composed of particles derived from the decomposition of greenstones and basalts, consists principally of grains of feldspar and hornblende, which have commonly lost all their external crystalline appearance. Quartzose grains and mica flakes derived from other sources are, however, often mingled with those substances in such sandstones, and serve, even in the most crystalline-looking varieties, to distinguish them from trap rocks.

The difference between a " trappean or volcanic ash," and a " trappean or volcanic sandstone," consists in this, that the materials of the ash were derived from the igneous outburst, and were deposited at the same time with the trap or lava from which they were derived, or immediately before or after that was poured out; whereas the trappean sandstone is merely the result of the abrasion and erosion of an igneous rock at some long subsequent period, when it became exposed to the action of moving water, together with the other rocks among which it lies.

In some cases doubtless, it may happen that " trappean sandstones," or " volcanic grits," put on the appearance of trappean or volcanic " ashes ;" and it would then be impossible to distinguish between the two kinds of rock, and say which accompanied the igneous outburst, and which was derived from the subsequent abrasion of the cooled igneous rock. These instances, however, are more rare than they might be supposed to be.

Distinction between Sandstone and Gritstone.—The difference between sandstone and gritstone is a vague and indeterminate one, which must necessarily be the case when the things themselves are so various and often capricious in composition and texture. The term gritstone is perhaps most applicable to the harder sandstones, which consist most entirely of grains of quartz, most firmly compacted together by the most purely siliceous cement. The angularity of the particles cannot be taken as a character, since the rock commonly called " millstone grit " is generally composed of perfectly round grains, sometimes as large as peas, and even larger ; the stone then commencing to pass into a conglomerate.

Local Terms.—There are many local terms used by quarrymen and miners for different varieties of sandstones :

Rock is used generally to denote any hard sandstone.
Rotch, or *roche*, is generally used for a softer and more friable stone.
Rubble is rough angular gravel, either loose or compacted into stone.
Hazel is a north of England term for a hard grit.
Post is a northern term for any bed of firm rock, generally sandstone.
Peldon is a South Staffordshire term for a hard, smooth, flinty grit.
Calliard,* or *galliard*, is a northern term for a similar rock.
Catsbrain, the form of calcareous sandstone in which the rock is traversed by little branching veins of carbonate of lime.
Freestone is a term in general use, which is often applied to sandstone, but sometimes to limestones, and even to granite, as in the counties of Dublin and Wicklow. It means any stone which works equally *freely* in every direction, or has no tendency to split in one direction more than another.
Flagstone, on the contrary, means a stone which splits more freely in one direction than any other, that direction being along the original lines of deposition of the rock. These stones are ordinarily sandstones, though often very argillaceous, and some flagstones are perhaps rather indurated clay in thin beds than sandstone. Thin-bedded limestones may likewise often be called flagstone.

Consolidation of Sandstone.—Sandstone, like conglomerate, may have been consolidated either by simple pressure continued for a long period of time, by pressure combined with an elevation of temperature, by the infiltration of mineral matter in solution, or by the partial fusion or solution, and subsequent reconsolidation of some of the particles composing it, or lastly, by a combination of two or more of these actions.

Some of the loose tertiary† sands of the north of France, such as

* Mr. Page, in his Advanced Text-book, which on several accounts is well worthy of the student's perusal, opposes the introduction of these local terms. I would, on the contrary, recommend their wider and more general use, not only as facilitating the intercourse between scientific geologists and our working brethren of the hammer, but as being often in themselves more definite and precise in their shades of meaning, as well as shorter, than our cumbrous periphrases of Latin terms. Many good, short, clear, and genuine Saxon names for natural objects, have been most unadvisedly allowed to fall into desuetude. As an instance, we need only mention the following for forms of ground:—

Scar or *Scaur*, A long line of cliff.
Torr, A rocky pinnacle.
Lowe, A round bare hill,—the Welsh *moel*.
Cleugh, A roundish mountain glen, the termination surrounded by steep hills.
Strath, The alluvial flat in the bottom of a valley.
Fell, A flat topped range of hills, whether a ridge, or the edge of a table-land.
Tarn, A lake in a cleugh.

† The term "tertiary," is one that will be explained hereafter, it relates to the period at which the rock was formed, and has no reference to the quality or nature of the rock.

the Sable de Fontainebleau, and the Sable de Beauchamp, exhibit these actions in a very remarkable way.

The Sable de Fontainebleau is a pure white siliceous sand. It is covered in some places by beds of a freshwater limestone called the Calcaire de Beauce. Water containing carbonate of lime in solution, derived either from this limestone, or from other sources, percolates through the sand, and deposits the lime, binding the sand either into globular concretions, or even into rhombohedral crystals, such as carbonate of lime ordinarily forms. Besides these smaller concretions, other large parts of the sand have been compacted together, either at the time of deposition, or subsequently, into a very hard white gritstone, which is extensively used as a paving stone in the districts where it occurs. This Grès de Fontainebleau forms picturesque crags and precipices, all the more striking perhaps, from their contrast with the loose and easily removed sand in which the beds and other irregularly formed masses of the consolidated rock occur. The cementing substance of this sandstone is not always carbonate of lime, since in some cases the quartzose grains appear to be bound together by a siliceous cement, as if the percolating water had contained dissolved silica. This is obviously the case in one variety, a glittering rock being produced, greatly resembling ordinary quartzite, only more white and lustrous; this variety is called "grès lustrée," or lustrous grit.

The Grès de Beauchamp consists of similar locally consolidated and semi-concretionary lumps of sandstone, occurring here and there in loose sand. On the plains north of Meulan, these lumps of gritstone are discovered by "sounding" or piercing the loose sands with an iron rod, and they are then extracted and broken into square blocks, and used for forming the roads of the country.

These tertiary grits are often as hard and intractable, and break with as splintery a fracture under the hammer of the geologist, as the grits he is accustomed to meet with among the oldest rocks of the British mountains.

Gradations from Sandstone into Clay.—When among the materials of a sandstone there occur any containing a notable proportion of alumina, which may be known by the earthy odour given out when the rock is breathed upon, we have the constituents for the formation of clay, and it only remains for those materials to be ground down into fine powder and mixed with water, either naturally or artificially, for clay to be produced. While all or any considerable portion of the rock remains in the form of distinct grains, we might call it an *argillaceous sandstone;* the passage from that to a sandy clay, and then to a pure clay or shale, being often an insensible one.

53. *Clay.*—Perfectly pure clay has been already described as a hydrated silicate of alumina. This is the substance known as "kaolin,"

or "porcelain clay," derived from the decomposition of feldspar, from which the silicates of potash, soda, etc., have been washed out. In some granitic districts, the decomposed granite yields this substance, which is carried down by water, and deposited in hollows, the quartz and mica being often left behind in the state of loose sand.

The ingredients of pure porcelain clay are also sometimes derived from other rocks, as at Rostellan, in Cork Harbour, where the highly inclined bottom beds of the Carboniferous limestone afford them in considerable abundance. The rock is a siliceous and argillaceous limestone (though no distinct nodules or seams of chert are visible in the adjacent beds), and over one small district the lime has been almost entirely removed, leaving the silica and alumina behind in the state of a crumbling powdery mass, which is rather largely exported to the English potteries.

Common clay, besides being mixed in variable proportions with sand, is often largely coloured with oxide of iron, and mingled with many impurities. Any very finely divided mineral matter, which contains from ten to thirty per cent of alumina, and is consequently "plastic," or capable of retaining its shape on being moulded and pressed, would commonly be called clay.

These clays have a number of varieties, of which the following are the principal :—

Pipe clay, free from iron, white, nearly pure.

Fire clay, nearly or quite free from iron, and from lime or alkalies, often containing carbon, which does not, however, prevent its forming bricks that will stand the heat of a furnace. It is probable that in good fire-clays the silica and alumina exist in just that definite proportion which would form a true silicate of alumina.

Shale, regularly laminated clay, more or less indurated, and splitting into thin layers along the original laminæ or planes of deposition of the rock. It was formerly called *slate clay*, as distinguished from *clay slate*. The colliers' and quarrymen's terms for shale are *Bind*, or *Bluebind*, *Metal*, *Plate*, etc. When very fine, and containing a large proportion of carbonaceous matter, the collier calls it *Batt** or *Bass*, the geologist carbonaceous (or bituminous) shale, and the coal merchant often "slate." In Scotland the collier's term for shale is "blaes," or "blues," the shales being often bluish gray. When lumpy, they are called "lipey blaes." Black, argillaceous shales (or batts) are called "dauks ;" "fekes," or

* This term of "batt" is commonly applied in South Staffordshire to a lump of shaly coal, which will not continue to burn in the fire, and therefore soon becomes ash, and is consequently of little worth, the word has gone out of general use in the English language except in composition, where it is retained in the word "brick-bat" for the broken end of a brick.

gray fekes," seem to be sandy shales such as would be called "rock binds" in South Staffordshire.—(See *Williams's Mineral Kingdom.*) In the south of Ireland carbonaceous shale is called "kelve," or "pindy" and indurated slaty shale is termed "pinsill," or "pencil," as it is used often for slate pencils. "Slig or sliggeen" is also used indiscriminately for shale and slate in the south of Ireland.

Clunch is a common name for a tough, more or less indurated, clay, often very sandy.

Loam is a soft and friable mixture of clay and sand, enough of the latter being present for the mass to be permeable by water, and to have no plasticity.

Marl is properly calcareous clay, which, when dry, breaks into small cubical or dice-like fragments. Many clays, however, are commonly but erroneously called marls, which do not contain lime.

Shell marl is the marl found at the bottom of an old pond or lake, obviously formed from the decomposition of shells, some of which may often be seen in it.

Argillaceous flagstone is an indurated sandy clay or clayey sandstone, which splits naturally into thick slabs or flags.

Clay slate is a metamorphosed clay, differing from shale in having a superinduced tendency to split into thin plates, which may or may not coincide with the original lamination of the rock. It will be more particularly described among the metamorphic rocks.

Mud and *silt* are the incoherent and quite unconsolidated materials of some form of argillaceous rock, either clay, shale, loam, or marl, according to circumstances.

Clay-rock is a name that is sometimes required to designate a highly indurated mass of pure clay, not soft enough to be plastic without grinding and mixing in water, and not laminated as shale, nor cleaved as slate.

CHAPTER VI.

AQUEOUS ROCKS, CHEMICALLY AND ORGANICALLY FORMED.

Preliminary Observations on their Origin.

BEFORE entering on the description of these rocks, it will be useful briefly to consider the nature and action of the forces concerned in their production. I shall take as my principal guide in this examination Bischof's "Chemical and Physical Geology," as translated for and published by the Cavendish Society.

Carbonate of Lime.—When speaking of the mineral Calcite, it was mentioned that carbonate of lime is nearly insoluble in pure water, but that if the water contain carbonic acid gas, the mineral is easily dissolved by it, either in consequence of some special solvent power in water so impregnated, or in consequence of the carbonate being converted into a soluble salt (never yet seen in a solid state) in the form of a bicarbonate or sesquicarbonate of lime.

Carbonic Acid Gas in Water.—Rain water and snow contain small quantities of carbonic acid derived from the atmosphere, and acquire more in sinking through the soil.

If water in sinking into the earth meets with carbonic acid gas, rising from the interior, it becomes saturated with it, and carbonated springs are produced. The waters of springs, rivers, and lakes, therefore, always contain some, and probably a very variable amount of carbonic acid gas.

The waters of the European seas, according to Vogel and Bischof, contain from 7 to 23 parts by weight of carbonic acid gas in the 100,000 of water. But from experiments made in the French ship "Bonité," in the South Sea and Indian Ocean, only from 0.4 to 3.0 parts by weight in the 100,000.—(*Bischof*, vol. i., p. 115, *note.*) It was apparently established, however, by the latter experiments, that the quantity of air, and especially of carbonic acid gas, increased with the depth from which the water was taken.

Carbonate of lime in fresh water.—The quantity of carbonate of lime held in solution by water containing carbonic acid gas is likewise very variable. In springs it may occasionally reach the point of saturation, which is about 105 parts in the hundred thousand.

In the rivers of Great Britain and Western Europe, the quantity of mineral matter held in solution varies from 4 to 55 parts in 100,000 parts of water, the mean quantity being 22. Of this mineral matter one half is commonly carbonate of lime, the least proportion, or 35 per cent, being found in the Loire, the greatest 82 to 94 per cent in the Rhone, at Lyons. The quantity of mineral matter in the Thames, near London, is 33 in the 100,000 parts of water, 15 of which, or 46 per cent, are carbonate of lime. Bischof calculates that if the mean quantity of carbonate of lime in the Rhine be assumed as 9.46 in 100,000 of water, which it is at Bonn, then, according to the quantity of water estimated by Hagen to flow at Emmerich, enough carbonate of lime is carried into the sea by the Rhine, for the yearly formation of three hundred and thirty-two thousand millions of oyster shells of the usual size. If we allow two square inches for each oyster to stand upon, and that three oysters one above another would be one inch high (quantities within the truth), then this number of oysters would form a cube of 560 feet in the side, or they would make a square layer a foot thick and upwards of two miles in the side.

Carbonate of Lime in the Sea.—Notwithstanding the vast quantity of carbonate of lime thus carried down into the sea, observation shews that the quantity to be found in sea water is commonly very small. In most analyses of sea water it is not mentioned at all. Sea water from Carlisle Bay, Barbadoes, contained 10 parts in 100,000 ; sea water from between England and Belgium, only 5.7 parts in 100,000. In the open sea, at a distance from any land, it is said to be rarely if ever discoverable by analysis.

The smallness of the quantity to be found in sea water, compared with that in almost all rivers, is doubtless owing to the quantity of carbonate of lime constantly abstracted from sea water by marine animals, in order to form their shells and other hard parts.

When we consider the vast number and variety of fish and of mollusca, crustacea, echinodermata, and polyps that inhabit the sea, and especially when we look at the enormous bulk of the coral-reefs that are found within the tropics, we shall be in no danger of under-estimating the vast amount of carbonate of lime annually abstracted from the ocean. That it is abstracted more in one part than another, and yet the ocean maintains a nearly equal average, will not be surprising when we reflect on the extent of the great currents that traverse the sea, and look upon the entire ocean as one vast, slowly circulating system of moving water.

Formation of Limestone from Fresh Water.—When water containing carbonate of lime in solution suffers from evaporation, each drop of water loses both water and carbonic acid gas, thus becoming gradually saturated with the carbonate of lime without gaining any increase in

solvent power.* When, then, the evaporation is continued beyond the point of saturation, some of the dissolved carbonate of lime must necessarily be deposited in a solid form on the solid substance over which the water passes, or on that which it has previously deposited. Drops of such water hanging from the roof of a cavern, or other similar place, may be observed to be coated over with a delicate film of carbonate of lime, like the finest tissue paper. This gradually forms a little tube, which may be seen sometimes to acquire a length of some inches, still retaining all its fragility, until water, trickling down the outside of it, strengthens it by the addition of successive external coats.

Water, then, trickling from the roof, or down the sides, or along the floor of limestone caverns, will form long icicle-like pendants hanging from the roof, or columns rising from the floor, wherever the water continues to drop long enough in one particular spot. Vertical sheets of it may even be formed when the water oozes from a long joint or crevice in the roof. The part hanging from the roof is called *stalactite*; that on the floor *stalagmite*. Stalactites, even when some feet long, and several inches in diameter, are often found with the little original central tube still open, since even if water pass down it, no evaporation can take place in it.

The limestone thus formed is commonly white or pale yellow, subcrystalline, often fibrous, and, when thin, semi-transparent or translucent. Some stalactites, while they retain their concentric rings, shewing the way in which they were formed by coat over coat, are nevertheless perfectly crystalline internally. I have, indeed, never seen any altered limestone so largely and beautifully crystallised as are some of the stalactites from the caves near Mitchellstown, in the south of Ireland, each crystal passing through many concentric coats of the stalactite.

Stalactites may often be seen under the arches of bridges, vaults, or aqueducts, especially if the stone of which they are built be limestone. Sometimes they are even derived from the carbonate of lime contained in the mortar or cement used in their construction.

Travertine, or *calcareous tufa*, is deposited by exactly the same process on the margins of springs or on the banks of rivers and the sides of waterfalls, or wherever water containing carbonate of lime in solution is brought into circumstances where rapid evaporation can take

* Bischof (vol. iii., p. 171) says that the maximum amount of carbonate of lime that can be dissolved in water saturated with carbonic acid is 0.1 per cent, but that water containing only one-tenth as much carbonic acid as a saturated solution, would dissolve just as much carbonate of lime as a saturated solution would even if it were under high pressure. The existence of carbonated springs, therefore, is not at all necessary for the deposition either of stalactites, travertine, or calc spar in veins, since ordinary meteoric water will contain quite enough carbonic acid for the solution of carbonate of lime, even to saturation of the water with that mineral, while the less the overplus of the acid the more readily will the mineral deposition take place.

place. Sticks and twigs hanging over brooks often become coated with it ; and the incrustation of birds' nests, wigs, medallions, and other matters, by the action of what are called petrifying wells, is commonly known. In Italy, large masses of solid and beautiful travertine are deposited by some of the springs, so that it is used as a building stone. The Colosseum at Rome is built of stone thus formed. The name travertine is derived from the Tiber, meaning simply Tiber-stone. Bischof says that there are fifty springs near Carlsbad giving out 800,000 cubic feet of water in twenty-four hours, from which, according to Walchner's calculation, a mass of stone weighing 200,000 pounds could be deposited in that time.

Pipes to convey water, especially water from boilers, frequently become choked up by the deposition of limestone, and have to be renewed. In some manufactories, the deposition inside a pipe exhibits a regular alternation of one white layer between six dirty ones, and this white one is called the "Sunday streak," as marking the deposition on the day when no work was going on, and the water was consequently clean.

Fresh-water Limestones.—Those limestones which have been formed in fresh-water lakes, and are called fresh-water limestones, may nearly resemble travertine in their mode of origin, since there is nothing to forbid the supposition of the waters of lakes becoming so highly impregnated with dissolved carbonate of lime as actually to deposit it as a chemical precipitate. At the same time, most fresh-water limestones look more like the result of the deposition of a highly calcareous, rather clayey mud, than of a precipitate of pure carbonate of lime. They become then the extreme term of marl or calcareous clay, and may be the result either of the disintegration of shells, etc., or of the mechanical action of rivers on previously existing calcareous rocks, the calcareous mud thence derived being perhaps mingled with the detritus of other rocks in greater or less quantity.

Formation of Limestone in the sea.—Bischof states that the quantity of free carbonic acid gas contained in the sea, is five times as much as is necessary to keep in a fluid state the quantity of carbonate of lime to be found in it. He argues, therefore, that it is impossible for any carbonate of lime to be *precipitated in a solid form at the bottom of the sea by chemical action alone.*

It is clearly impossible for any evaporation of water and gas to occur to a sufficient extent in the sea for precipitation to take place, as it does from the waters just described. We are almost compelled, therefore, to conclude with Bischof, that all our marine limestones have been formed by the intervention of the powers of organic life, separating the little particles of carbonate of lime from the water and solidifying them, in order to enable them to form part of a solid rock.

There is of course the possibility that the sea once contained a much greater proportion of carbonate of lime than it does now, though this does not appear likely when we recollect that in the earliest and least fossiliferous of our formations, there is a much smaller proportion of limestone than in later and more fossiliferous rocks ; and that even in the oldest * limestones, organic remains are to be found.

If it be impossible that carbonate of lime should be deposited on the bottom of the sea by any mere chemical agency, it follows that we must look for its production to that cause which we know is capable of producing it, namely, the power possessed by the organs of animals. The shells of Molluscous animals consist chiefly of carbonate of lime, so do the crusts of the Crustacea and Echinodermata, and as we descend still lower to the Polyps and Foraminifera we meet with animals that secrete still larger quantities of that substance, not only larger in proportion to their own bodies, but much larger absolute bulks of it, in consequence of their numbers.

Although the quantity of carbonic acid gas in the sea is so great as to keep fluid all the lime which is already dissolved in it, and even a good deal more than sufficient for that purpose, yet it does not immediately exercise its solvent powers on the carbonate of lime that has been secreted by the organs of animals, since the organic structure seems to protect it for a time at least from the merely chemical action of the acid. Moreover, the concentration of so large a proportionate mass of carbonate of lime in comparatively small spaces, would require a long continued action of currents of sea water upon it, in order to re-dissolve it, since no portion of water could remove more than one-tenth per cent of its own bulk. (Bischof, vol. iii., p. 173).

In the extra-tropical seas, it would seem probable that Foraminifera and other allied animals are the most active agents in the secretion of carbonate of lime. In the series of sounding operations lately conducted across the Atlantic by the officers of the British and United States Navies, preliminarily to laying down the electric telegraph, it was found that large parts of the bed of the Atlantic were covered with a calcareous " oaze." Captain Dayman, R.N., in his Deep Sea Soundings (published by Potter, 31 Poultry, 1858) says, that " from the coast of Ireland † to 11° 15' west longitude the bottom is sandy, and the water gradually deepens to 90 fathoms. At the 12th degree the bottom is rocky, and the depth 200 fathoms, and from this to 13° 15' west longitude, there is an average depth of 400 fathoms with a muddy bottom. A sandy flat with a mean depth of 200 fathoms is found to

* In the highly altered limestones associated with gneiss and mica slate, we could hardly expect to find traces of fossils, even if they once contained them. Organic forms have, however, lately been discovered in altered limestone from some of the gneiss of Scotland.

† Valentia Harbour is in 10° 16' west longitude or thereabouts.

exist between 13° 30′, and 40° 30′ west longitude. In 14° 48′ west, we have 550 fathoms, *rock*, and in 15° 6′ west, 1750 fathoms, *oaze*."*

"Between the 15th and 45th degrees of west longitude, lies the deepest part of the ocean between Ireland and Newfoundland, varying from about 1500 to 2400 fathoms, the bottom of which is almost wholly composed of the same kind of soft mealy substance, which, for want of a better name, I have called oaze. This substance is remarkably sticky, having been found to adhere to the sounding rod and line through its passage from the bottom to the surface, in some instances from a depth of more than 2000 fathoms."

The space indicated equals a distance of more than 1300 miles, in which only two exceptions occurred to the above description of "bottom." In Trinity Bay, Newfoundland, the depth varied from 90 to 320 fathoms, the bottom being either bare rock or fine blue or green mud, sometimes containing stones.

Professor Huxley gives a description of the oaze derived from depths between 1700 and 2400 fathoms (or 10,200 and 14,400 feet) in the appendix to the pamphlet above mentioned. He says, "a singular uniformity of character pervades these soundings. As they lie undisturbed they form an excessively fine light brown muddy sediment at the bottom of the bottles in which they are preserved; but in this mud a certain slight grittiness can be detected, arising from the intermixture of minute hard particles (hardly ever exceeding $\frac{1}{50}$th of an inch in diameter). * * When a little of this mud is taken out and thoroughly dried, it becomes white or reddish white, and (though less white), closely resembles very fine chalk, and fully nine-tenths, as I imagine, by weight of this deposit consists of minute animal organisms called Foraminifera, provided with thick skeletons composed of carbonate of lime. Hence, when a dilute acid is added to the mud, a violent effervescence takes place, and the greater part of its bulk disappears.

Professor Huxley believes that 85 per cent of the whole belong to one species of the genus Globigerina; 5 per cent to other calcareous organisms of at most four or five species, and the remaining ten per cent consists partly of minute granules of quartz, and partly of animal and vegetable (diatomaceæ) organisms provided with siliceous skeletons and envelopes.

It will be seen from the foregoing description, that the materials for a continuous bed of limestone with flint nodules are now being deposited in the North Atlantic over a space which is 1300 miles in

* Captain Dayman says that this is "the greatest dip" or steepest inclination "in the whole North Atlantic ocean." The numbers given above indicate an "incline" of 1200 fathoms, or 2400 yards, in 18′ of longitude, which in latitude 52° may be taken as very nearly equal to 24,000 yards. This gives an inclination of 1 in 10, or about 6°, a slope which on dry land would not be too great for a carriage to drive up or down.

diameter, a distance equal to that from the west coast of Ireland to the borders of Russia, or from Paris to Constantinople. In the second pamphlet by Captain Dayman, published in 1859, describing the line of soundings taken to the Azores in 1858, he states that he found precisely similar oaze nearly down to latitude 45°, so that the deposit appears to be at least 600 miles broad.

Coral Reefs.—The solidification of carbonate of lime by the forces of life thus discovered to be going on in the depths of the North Atlantic, is doubtless equally active in the other oceans, both within and without the tropics. In many parts of the intertropical regions of the world, however, especially in the Indian and Pacific Oceans, another class of animals, namely, the Polyps, produce still greater effects. Polyps are merely soft gelatinous animals, consisting of little else than a small sac or stomach, with tentacles arranged round its margin to assist in supplying it with food. Some kinds of them form a common mass or body, a number of small individuals uniting to make a polypodom, out of which they grow, just as a number of individual buds exist in, or grow out of, a common vegetable body or tree, the compound body in each case increasing in consequence of the growth of the individuals belonging to it. Almost all these compound polyps secrete carbonate of lime, forming a solid compound skeleton or frame work called a coral.*

In almost all tropical seas encrusting patches or small banks of living coral are to be found along the shores, wherever they consist of hard rock, and the water is quite clear. These, M. Darwin calls Fringing reefs.

In the Indian and Pacific Oceans, however, far away from any land, huge masses of coral rock rise up from vast and often unknown depths just to the level of low-water. These masses are often unbroken for many miles in length and breadth ; and groups of such masses, separated by small intervals of deep water, occur over spaces sometimes of 400 or 500 miles long, by 50 or 60 in width. These often form large irregular rings or loops, and when they do not enclose any high land, they are called Atolls.

When the reefs encircle or front high land, with a navigable water channel between the land and their outer edge, they are called Barrier reefs. The barrier reef along the north-east coast of Australia is composed of a chain of such masses, and is about 1250 statute miles long, from 10 to 90 miles in width, and rises at its seaward edge from depths

* The coral-forming polyps are often popularly spoken of as coral-*insects*, and they are sometimes supposed to *build the coral* as the bee builds its comb. These terms are very misleading, as the coral cannot properly be said to be built by the animals that live on its surface, any more than the timber of a tree could be said to be built by the buds, or the shells and skeletons of animals to be built by the animals.

which in some places certainly exceed 1800 feet. (See voyage of H. M. S. Fly, vol. i., chapter 13).

It may be likened to a great submarine wall or terrace fronting the whole north-east coast of Australia, resting at each end on shallow water, but rising from very great depths about the centre, its upper surface forming a plateau, varying from 10 to 30 fathoms in depth, which is studded all over with steep-sided block-like masses that rise up to the level of low-water. These masses vary in size from mere pinnacles to an area of some miles, generally much longer than broad, and running more or less nearly across the direction of the prevailing wind. They are especially numerous and most linear along the edge of the great bank on which they rest, the passages between them being often very narrow, like irregular embrasures opened here and there through the parapet wall of a fortress. These " individual reefs " running along the outer edge protect the comparatively shallow water inside, and with the numerous inner reefs that are scattered over its space make it one great natural harbour. An idea of its extent may be gained by supposing it transferred to our own part of the world, and extended from Brest across the mouths of the English Channel and Irish Sea, round the west coast of Ireland to the extreme west point of Iceland, or curving along the shores of Scotland and the Shetland Islands up to the coast of Norway.

The " bottom," between the " inner reefs" of the great Australian barrier, when brought up by the dredge from a depth of fifteen or twenty fathoms, often looked very like the unconsolidated mass of some of the coarse shelly limestones to be found among the oolites of Gloucestershire. At other times the dredge came up completely filled with the small round Foraminifera, called Orbitolites,* and these organisms seemed in some places to make up the whole sand of the beach either of the coral islets or of the neighbouring shores. In the deep sea around, and in all the neighbouring seas, from Torres Straits to the Straits of Malacca, wherever " bottom" was brought up by the lead, it was found to be a very fine-grained, impalpable, pale olive-green mud, which was wholly soluble in dilute hydrochloric acid. This substance, when dried, would therefore be scarcely different from chalk, though it commonly was of a greener tinge. This fine calcareous mud may be partly derived, like the oaze of the North Atlantic, from the calcareous bodies of minute animals that live either on the surface or in the depths of the seas at the bottom of which it is found ; but much of it is doubtless derived from the waste of the coral reefs themselves.

Some fishes, according to Mr. Darwin (Coral Reefs, p. 14), browse

* These are either exactly the same as, or closely allied to the Nummulites of which some great masses of limestone are made up.—*See Dr. Carpenter's Papers in Phil. Trans.*, vol. 146, etc.

upon living coral, and all the great Holothuria (or Tripang), so abundant on the coral reefs of the Great Barrier and elsewhere, are always full of coral sand, on the animal matters in which they seem entirely to subsist. The mere process of digestion, then, carried on by these and other animals, must contribute much impalpable calcareous mud to the adjacent seas.

The tidal currents among the "inner reefs," and in the openings of the Great Barrier, are often excessively strong, running sometimes with an impetuous sweep, in the same direction, even for two or three days together, especially after great storms have driven large quantities of water into the space between the outer edge and the land.—(*Voyage of H.M.S. Fly*, vol. i., p. 19.)

The outer edge of the Great Barrier (and the windward side of all coral reefs) is always subject to the battering and pounding action of the most tremendous surf that can be imagined, since the long roll of the ocean swell falls suddenly on the upper edge of the great submarine wall, dashing upon it with almost inconceivable power, and roaring over the surface of the reef in huge breakers that are sometimes felt even all across it. At high tide especially, when the wind blows strongly on the reef, a vast quantity of water is thus thrown into the inner lagoon, which, as the tide falls, scours out all the outer channels and passages. Although the living coral flourishes most where the surf is heaviest, and the greatest masses of Mæandrina and Porites,* and other gigantic species, live only on the outer edge of the reef; yet if a mass, living or dead, be once detached from the rest, it is soon acted upon by these breakers, and ultimately triturated into calcareous sand or mud.

In addition to the Great Barrier just spoken of, all the sea between Australia, New Caledonia, and the Louisiade, is infested with coral reefs, so that Flinders called it the Coral Sea. As this space is 1000 miles wide and broad, we have here an area of something like a million of square miles over which carbonate of lime is being deposited in great sheets, and in bank-like masses, which are in some parts at least more than 1000, probably more than 2000 feet in thickness.

Those coral reefs, which may be called living reefs, consist of living corals only in parts of their upper surface, and along there outside rim, which is a mere film compared with their whole bulk. All the interior

* Rounded masses, or solid stools of Mæandrina, of 6 or 8 feet in diameter, are common among the detached blocks rolled up from the outer slope on to the reef. They may be seen just inside the surf, at low water, from a distance of one or two miles, and are spoken of by Flinders as "Turks' Heads." I once landed close to the edge of the Barrier, on the south side of the Blackwood Channel, in south latitude 11° 45′, on a continuous mass of Porites, which was at least 20 feet across, and seemed to pass downwards into the mass of the reef below water without any disconnection. It was worn into pinnacles above, so that two or three of us could stand in the different hollows without seeing each other. This formed part of a line of such masses that attracted our attention from a distance of three miles. They are marked as "rocks dry at *high* water" in the charts.

is composed of dead corals and shells, either whole or in fragments, and the calcareous portions of other marine animals. The interstices of the mass are filled up and compacted together by calcareous sand and mud, derived from the waste and debris of the corals and shells, and by countless myriads of minute organisms, mostly calcareous also. The living part, even of the upper surface of the reef, is that only which is never dry at low water. The part which is then exposed is composed of mere stone, which is often capable of being split up and lifted in slabs, bearing no small resemblance to some of our oldest limestones. These slabs and blocks, when broken open, are frequently found to have a crystalline structure internally, by which the forms and the organic structure of the corals and shells are more or less disguised and obliterated. A coral reef, then, of which a part is still living and in process of formation above, may internally consist of solid crystalline limestone—since it may well be there just as crystalline as many stalactites.

On the upper surfaces of some coral reefs small islands are formed, —the coral sand being drifted by the winds and waves till it forms a bank reaching above high-water mark. In some of these islands, the rounded calcareous grains are bound together into a solid stone by the action of rain water, which, containing a small quantity of carbonic acid, dissolves some of the carbonate of lime as it falls, but, being shortly evaporated, redeposits it again in the form of a calcareous cement. The stone thus formed is like a cake resting upon still incoherent sand below. Some of this stone, which was used for building a beacon tower on Raines' Islet, to mark an opening in the Great Barrier reef, presented very distinct examples of the oolitic structure presently to be mentioned, little minute grains and particles being enveloped in one or two concentric coats, like the coats of an onion. That this stone was not consolidated under water was proved by nests of turtles' eggs being found imbedded in it, evidently deposited by the animal when the sand was above water, and was loose and incoherent.

Raised coral reefs, in the islands of Timor and Java, were often internally as white and friable as chalk, though they had frequently a rougher and grittier texture, and weathered black outside. The weathered surfaces of these limestones, often at a height of two or three hundred feet above the sea, with their embedded shells of all descriptions, including a Tridacna of one or two feet in diameter, differed in no respect from some of the surfaces of the Great Barrier reef, where exposed at low water.—(*Voyage of H.M.S. Fly.*)

Guided by these facts and observations, we may form tolerably accurate notions of the mode of origin of all our marine limestones, and attribute to them an organic-chemical origin, taking into account, at the same time, how easily they may have been subsequently altered in texture by the metamorphic action either of water or of heat.

We must also bear in mind that, although the carbonate of lime may have been secreted and brought into a solid form from its aqueous solution by the action of animal life, yet that the original form it thus received has been retained in only a small part of it, the great mass having been subjected to the mechanical actions of erosion, trituration, and transport, to a greater or lesser extent, in the process of its conversion into calcareous mud, and deposition as beds of limestone.

Silica.—The aqueous deposition of silica is sometimes a purely chemical one, as in the case of the *siliceous sinter* deposited round the Geysers, or hot-springs, of Iceland, and round the hot springs of St. Miguel and Terceira, in the Azores, and the chalcedony round those of New Zealand. Cold-water springs also, in some instances, deposit siliceous matter; but in these the silica is generally combined with alumina, oxide of iron, and other bases. In all these cases, evaporation of the water takes place, and the silica is deposited in consequence of that evaporation. Bischof attributes the formation of quartz crystals in cavities, and of compact quartz in veins, to the total evaporation of water containing silica in solution, and trickling down the sides of such cavities, and it is difficult to imagine any other method for their formation, among aqueous rocks at all events. He points out the impossibility of ascending springs depositing the quartz, inasmuch as those must be full of water, and therefore total evaporation of successive films of water could not take place. He attributes the formation of quartz crystals in drusy cavities to a similar evaporation of water containing silica, that has filtered through the adjoining rock. Agates, chalcedony, etc., shew very distinctly the successive deposition of films of silica.

Formation of Silica in the Sea.—To account for the deposition of silica on the bed of the sea, where evaporation is not possible, we are compelled, as in the case of limestone, to call in the aid of the powers of animal life. The minute shells of many of the infusoria are almost entirely composed of silica, which they have extracted from the water of the sea. Some kinds of rock, such as the tripoli, or polishing slate, are entirely made up of these microscopic substances, some beds thus formed being many fathoms in thickness and many miles in extent.

All seas, from the equator to the poles, abound with these minute organisms. They have been found living even in ice. The phosphorescence of the sea is due to the presence of organic beings, a large proportion of which are siliceous-cased infusoria, whether belonging to the animal or vegetable kingdom. According to Ehrenberg, there are formed annually in the mud deposited in the harbour of Wismar, in the Baltic, 17,946 cubic feet of siliceous organisms. Although it takes a hundred millions of these animalcules* to weigh a grain, Ehrenberg

* In using the terms "animalcules" and "infusoria," it must be borne in mind that biologists now believe many of them, such as the Diatomaceæ, to be vegetables.

collected a pound-weight of them in an hour. So prolific are they, moreover, that "a single one of these animalcules can increase to such an extent during one month, that its entire descendants can form a bed of silica 25 square miles in extent, and $1\frac{3}{4}$ foot thick.* As a parallel to Archimedes, who declared he could move the earth if he had a lever long enough, we may say :—Give us a mailed animalcule, and with it we will in a short time separate all the carbonate of lime and silica from the ocean." The silica thus rendered solid may either be deposited alone, or may be mingled with the calcareous matter deposited on the bed of the sea by the methods just now mentioned. If the siliceous be diffused in a fine state of division pretty equally through the calcareous matter, it may perhaps be consolidated in that state of diffusion producing a siliceous limestone, or it may, in obedience to certain chemical laws, segregate itself, more or less completely, from the calcareous matter, and form either distinct layers and veins, or concretionary balls and nodules. The presence of a body, itself consisting largely of silica, such as many sponges, will facilitate and determine this process, affording a centre of attraction for the siliceous particles to collect around it from the adjacent matter.†

These views of the organic origin of most marine limestones and flints are corroborated by the fact, which we shall presently describe, of almost all great masses of limestone being accompanied by siliceous portions of a peculiar character, such as are rarely or never to be found in any other rocks except limestone.

Carbonate of Magnesia.—Magnesia occurs in sea water in the form of chloride of magnesium and sulphate of magnesia. Bischof says that the water of the Mediterranean, which contains the largest amount of magnesian salts, has 0.25 per cent of the former, and 0.625 of the latter (vol. iii., p. 161). Of the salts dissolved in sea-water,‡ 8 to 15 per cent consist of chloride of magnesium, and 6 to 16 per cent of sulphate of magnesia.—(*Bischof*, vol. i., p. 99 to 105.) From the quantity of free carbonic acid in the sea, it is plain that these might be converted into carbonate of magnesia, but that if so, it would be kept in solution as a bi-carbonate (or sesqui-carbonate), as in the case of carbonate of lime.

* Bischof, vol. i., p. 188. There is a slight mistake in the English translation, in which the words "millions of" have been omitted after the figures 65,000. If we make the calculation in English weights and measures, it appears to me it will give 1,143,000,000 of cubic feet, or 41 square miles 1 foot high, or a square of that height measuring nearly $6\frac{1}{2}$ miles in the side.

† Mr. Bowerbank has proved the presence of sponge particles in many flints and cherts, and refers them all to that origin.

‡ Bischof also tells us (vol. iii., p. 178) that the quantity of carbonate of magnesia carried down by the Rhine into the sea in the course of twenty-four hours, is 4,621,956 lbs., sufficient to yield 10,087,202 lbs. of dolomite, consisting of equal equivalents of the carbonates of lime and magnesia. This quantity would be equal to a square mass 1 foot high and 239 feet in the side every day, or 4560 feet in the side in the course of a year.

All that has been said, therefore, as to the necessity for calling in the aid of organic life to solidify carbonate of lime from the waters of the sea, "holds good in regard to carbonate of magnesia, and the more so, since this salt always separates later than carbonate of lime, even from fluids which have undergone a very high degree of evaporation."—(*Bischof*, vol. i., p. 117.)

There is, however, this difficulty in this view:—The carbonate of lime is largely separated from the sea water by being made to enter into the composition of the hard parts of marine animals in overwhelming proportion, whereas the percentage of carbonate of magnesia to be found in the hard parts of corals and mollusca does not usually exceed 1 or 2 per cent. Neither do we know any class of animals that secrete any much greater quantity of magnesia, as some of the infusorial animals secrete silica. Yet in many widely-spread magnesian limestones the quantity of magnesia is almost equal to that of lime, and the proportion is frequently as much as 20 to 30 per cent. Forchammer, however, found 2.1 per cent in Corallinm nobile, 6.36 per cent in Isis hippuris, and 7.64 per cent in some species of Serpula, while 16 to 19 per cent have been found in some species of Millepore.—(*Geol. Reports of Canada for* 1857. Mr. Sterry Hunt.)

Magnesian limestones are, however, generally poor in organic remains, though this may be the result of their more perfect crystallization and mineralization by which the organic structure has been obliterated, rather than of the absence of organic beings from the original deposit. Mr. Sterry Hunt has demonstrated the possibility of the chemical deposition of Dolomite in isolated lakes or seas, where great evaporation is taking place, but it is difficult to imagine many of our dolomites to have been formed in such situations.

In whatever way effected, it is true that magnesian limestones, containing various proportions of lime and magnesia, have been *deposited* originally as magnesian limestone at the bottom of the sea, sometimes in large quantities, and over considerable areas.

It is equally true that pure carbonate of lime has in many cases been subsequently converted into dolomite or magnesian limestone by chemical metamorphic action.

Sulphate of Lime and Rock-salt (*chloride of sodium*) are undoubtedly chemical precipitates, and we are here again met by the same difficulty as before, in assigning a proximate cause for that precipitation in the open sea. If we could imagine a portion of sea water separated from the ocean, and left, as a shallow lagoon, to gradually dry up, there would be no difficulty in the case.

Bischof gives the following as the average composition of the salts of the sea water (vol. i., p. 379):—

	Percentage.
Saline contents of sea-water . .	3.527
Consisting of—	
Chloride of Sodium (common salt) .	75.786
Chloride of Magnesium . . .	9.159
Chloride of Potassium . . .	3.657
Bromide of Sodium	1.184
Sulphate of Lime (gypsum) . .	4.617
Sulphate of Magnesia (Epsom salts) .	5.597
	100.000

He tells us, too, that when sea water is evaporated, the point of saturation for sulphate of lime is much sooner reached than that for rock-salt; 37 per cent of the water being required to be removed in the one case, and 93 per cent in the other. Gypsum, therefore, must always be deposited before rock-salt, and it is possible for the point of saturation to be reached for gypsum in many cases without that for rock-salt being attained. This may be the reason why, although the sea contains sixteen times as much salt as it does gypsum, that the latter more frequently occurs as a mineral deposit than the former, though not often in such great masses.

It has been suggested that, in consequence of the greater specific gravity of sea water increasing with the quantity of salt it contains, and the evaporation at the surface causing a perpetual increase in the salt of the surface water, that a part of the water which holds a larger quantity of salt in solution than the rest, may sink to the bottom of the sea, and that this process may be continued until the lower strata be saturated with salt, and precipitation take place. The circulating currents of the ocean, however, keep up such a constant mixture of its waters, as would seem altogether to prevent this action; and even in deep hollows and basins, such as the Mediterranean, separated by a shallower bar (1320 feet at the deepest) from the bed of the ocean, the *traction* of the currents passing over this is sufficient, according to Maury (Physical Geography of the Sea), to prevent any accumulation of denser and salter water at the bottom.

In isolated seas, such as the Dead Sea, where the water is entirely saturated with salt, evaporation doubtless causes a precipitation on its bed (*Bischof*, p. 400). Here, and in shallow lagoons, such as the limans of Bessarabia, south of Odessa, that dry up in summer, we have the formation of rock-salt going on before our eyes.

In fresh-water lakes sulphate of lime may be deposited, either directly, the water becoming saturated with that substance, or in consequence of springs or rivers containing sulphuric acid, which convert into sulphates the carbonates of the marls and calcareous muds already

deposited. In some instances chemical reactions, such as the oxidation of iron pyrites (bisulphuret of iron), and that of sulphuretted hydrogen, may be supposed to take place, producing sulphuric acid, which immediately acts on any carbonate of lime that it can reach.

Carbon may be looked upon as essentially an organic element. Wherever we find carbonaceous matter in rocks, therefore, we may suspect it to have been derived from organic substances. Even the diamond is now believed to be a crystallized gum, or other vegetable product, and graphite may in like manner be looked upon as a possible, if not a probable, result of the metamorphosis of either animal or vegetable substance into a mineral. Even the purest graphite contains traces of earthy matter, diminishing its claims to be considered an original independent substance.

Carbon enters into the composition of *animal* matter, but its most abundant source is the *vegetable* kingdom.

Again taking Bischof as a guide in the explanation of the conversion of the organic substance wood into the rock which we call coal, I abstract some of his results in the following remarks (see Bischof, vol. i., chap. 15) :—

The following Table contains the mean composition of Wood, the mean of three analyses of Peat, of four sets of analyses of Lignite, comprising twenty specimens, of sixty-seven analyses of Coal, and the extreme of several analyses of different kinds of Anthracite.

COMPOSITION OF CARBONACEOUS SUBSTANCES

	Carbon.	Hydrogen.	Oxygen and Nitrogen.*	Earthy Substances or Ash.	
				Min.	Max.
Wood . .	49.1	6.3	44.6	—	—
Peat . .	54.1	5.6	40.1	4.6 to	10.0
Lignite . .	69.3	6.6	25.3	0.8 to	47.2
Coal . .	82.1	5.5	12.4	0.24 to	35.5
Anthracite .	95.0	3.92	3.45	0.94 to	7.07

It will be at once perceived that the earthy substances, or ash, must be looked upon as accidental extraneous mixtures which have not been included in the percentages of the essential constituents of the carbonaceous substances. While, too, the mean composition has been given for peat, lignite, and coal, the extreme has been taken for anthracite, to contrast with that of wood, which may be looked on as the extreme in the other direction.

* The quantity of nitrogen is very small, so that for our purposes it may be neglected.

The difference between coal and anthracite is an arbitrary distinction which would vary in the opinion of different observers and experimenters, one man, perhaps, calling the very same substance coal which another would consider to be anthracite.

The first thing we learn from the examination of this table is, that the rocks anthracite and coal are essentially different in composition from any other rocks that have hitherto been spoken of. We have not hitherto found any rock more than half of which is pure carbon.

The next thing we learn is, that there is a regular gradation from the chemical composition of these rocks through that of lignite and peat (or turf) into that of actual wood or living vegetable substance.

No other rock exhibits anything approaching to this composition, which is in itself a strong "a priori" argument in favour of the rock coal having been derived from plants, in the same way that we can see peat derived from plants before our eyes, and feel sure that lignite is so derived, because it retains the vegetable fibre, and often the form, of wood.

The change from one substance to the other seems to take place chiefly by the abstraction of oxygen, and a certain amount of condensation or diminution of bulk in the resulting mass.

If, therefore, we suppose wood (or vegetable matter) buried under accumulations of more or less porous rock, such as sandstone and shale, so that it might be partially decomposed, and some of its elements enter into new combinations, either gaseous or liquid, those combinations always using up a greater quantity of oxygen and nitrogen than of carbon and hydrogen, or of oxygen and hydrogen than of carbon, we should have the exact conditions for the transformation of vegetable matter into coal.

This process might naturally take place in four ways :—

1*st*, By the separation of carbonic acid gas (consisting of two equivalents of oxygen and one of carbon $= CO^2$) and carburetted hydrogen (consisting of four equivalents of hydrogen to two of carbon $= C^2H^4$) from the elements of the wood.

2*d*, By the separation of carbonic acid from the elements of the wood, and the oxidation of some of the hydrogen (*i.e.*, its conversion into water $= HO$) by combination with external oxygen.

3*d*, By the separation of both the carbonic acid and the water from the elements of the wood.

4*th*, By the separation of all three substances, carbonic acid, carburetted hydrogen, and water, from the elements of the wood.

The loss of carbon is greatest in the first case, and least in the third, being always greater in proportion to the quantity of carburetted hydrogen which is disengaged.*

* See also a very clear explanation of this subject in *Ronald's and Richardson's Chemical Technology*, vol. i., p. 31.

When wood or vegetable matter, then, is buried under circumstances which allow of the extrication of these substances from it, in the course of its decomposition, it *must* become converted into coal; the extreme result of the process being to give us first anthracite, containing perhaps 94 per cent of carbon, and finally graphite, which is either pure carbon itself, or that substance mingled with others which are here excluded from consideration as not being among the elements of wood, and which it may have acquired, during the process of conversion, from external sources.

The great quantities of carbonic acid gas (choke damp) and carburetted hydrogen (fire damp) met with in coal mines, shews the fact of the large extrication of these substances, and corroborates, if need were, this explanation. Reservoirs of these gases in a highly compressed state are often found to be pent up in the crevices and cavities of coal beds, and are the cause, when tapped, of many of the accidents which take place. Some beds of coal are so saturated with gas, that, when cut into, it may be heard oozing from every pore of the rock, and the coal is called "singing coal" by the colliers.

Bischof shews, that "under circumstances otherwise similar, the conversion of vegetable substances into coal takes place in the same way, whether they are mixed with much or little earthy matter." He also believes, from Kremers' and Taylor's investigations into the nature of the ash of coal, that there was an *intimate mixture* of vegetable and earthy substances, and that coal containing earthy matter could not be formed from compact wood without previous decay having taken place (vol. i., p. 269). He seems to suppose that, in many instances, this decay has gone so far as to convert the vegetables into "mould," which has been drifted as a kind of vegetable mud, and when mixed with earthy matter, deposited under water in the place where we now find it as coal.

As to the circumstances which caused such great masses of vegetable matter that once grew on the surface of the earth to be buried, and often so deeply buried, in the interior of its crust, we will defer their discussion to a future chapter, after having described the movements that take place in the earth's crust.

General Conclusion.—The student will have learnt from what has been stated in this chapter, that in addition to the ruder mechanical forces which are always necessarily at work in modifying the surface of the earth, there are other more subtle agencies engaged in the same operation. Chemical force acts not only through the power of heat, but also through those of liquids and gases, in separating the constituents of rocks and earths, and diffusing them through the air and the waters of the globe, and, where the necessary conditions are present, causing those constituents to enter into new combinations and

to produce new rocks, or to reproduce previous forms of combination in new situations. It also prepares many materials which enter into the composition of rocks for the action of organic life, which, by a newer and a higher power than a merely chemical one, makes use of the materials thus made ready for it, and moulds them into various forms, which contribute towards the elaboration of the complex structure of the crust of our globe.

Vegetables chiefly existing in the air extract from it the substance carbon, and by the hidden processes of life, compel it to enter as a solid and visible substance into the composition of their own bodies.

Animals living in the sea in like manner extract lime from its invisible and almost inappreciable solution, and similarly render it a solid constituent of many parts of their own structure.

Land animals and aquatic plants equally secrete these and other substances; air and water in all cases combining to produce the results, and the vital energy of plants and animals reciprocally acting and reacting in support of each other.

Mineral matter is thus, after being subject to the destructive agency of mechanical force, and after apparently disappearing under that of chemical action, brought back to the solid form by the power of life, and having served the purposes of organic beings, is delivered over as dead matter to enter again into the merely mineral composition of the earth, and ultimately to perform the same eternal round at some future and perhaps far distant period.

We build our houses by aid of materials derived from animals that perished thousands of ages ago, and we warm and light them from those of equally long perished plants, restoring to the atmosphere the carbon that floated in it at a still earlier period, and ultimately to the dust, and then to the waters of the earth, the lime that was formerly dissolved in them.

Description of the Chemically and Organically formed Aqueous Rocks.

54. *Limestone* may be hard or soft, compact, concretionary, or crystalline, consisting of pure carbonate of lime, or containing silica, alumina, iron, etc., either as mechanical admixtures, or as chemical deposits along with it.

Different varieties of limestone occur in different localities, both geographical and geological, peculiar forms of it being often confined to particular geological formations over wide areas, so that it is much more frequently possible to say what geological formation a specimen was

derived from, by the examination of its lithological characters, in the case of limestone, than in that of any other rock.*

Compact limestone is a hard, smooth, fine-grained rock, generally bluish gray, but sometimes yellow, black, red, white, or mottled. It has either a dull earthy fracture, or a sharp, splintery, and conchoidal one. It will frequently take a polish, and when the colour is a pleasing one, is used as an ornamental marble.

Crystalline limestone may be either coarse or fine-grained, varying from a rough granular rock of various colours, to a pure white, fine-grained one, resembling loaf sugar in texture. This latter variety is sometimes called *saccharine*, sometimes *statuary marble.* The crystalline structure of limestone is either original, when it is often found that each crystal is a fragment of a fossil, or it has been superinduced by metamorphic action on a limestone formerly compact.

Chalk is a white, fine-grained limestone, sometimes quite earthy and pulverulent, sometimes rather harder and more compact, as the chalk of the north of Ireland, and some of that of the north of France.

Oolite is a limestone in which the mineral has taken the form of little spheroidal concretions, and the rock looks like the roe of a fish, from which its name, signifying *egg*, or *roe*-stone, is derived. These little concretions have several concentric coats, sometimes hollow at the centre, sometimes enclosing a minute little grain of siliceous, or calcareous, or some other mineral substance. It is commonly of a dull, yellow colour, but gray oolitic limestone is not unfrequent. Its peculiar structure gives it the character of a freestone, working easily in any direction ; whence its value as a building stone.

Bath stone, Portland stone, Caen stone, are well-known examples of oolitic limestone, but the oolitic structure is by no means confined to what is known as the Oolitic formation, since many parts of the Carboniferous limestone of Ireland † are equally oolitic and highly valued as building stone, and the structure occurs even among the recent limestone of coral reefs.

Pisolite is a variety of oolite, in which the concretions become as large as *peas.* A pisolitic limestone near Cheltenham is spoken of by the quarrymen as the "*pea grit.*" It is a structure not confined to limestone, however, as other rocks or minerals occasionally assume it.

* No experienced British geologist would be likely to confound characteristic specimens of the limestones of the Silurian, Carboniferous, Oolitic, and Cretaceous formations of Britain and Western Europe, while no one could pretend to distinguish with certainty from mere lithological characters between the argillaceous or arenaceous rocks of those different formations.

† The limestone in the neighbourhood of Edenderry in county Kildare, and large parts of the Carboniferous limestone of the counties of Limerick, Tipperary, Queen's County, and Mayo, are perfectly oolitic in structure, sometimes more regularly so than the majority of the oolites belonging to that which is called the Oolitic formation.

Many limestones are named from their containing some peculiar variety of fossil, as *Nummulite*, *Clymenia*, *Crinoidal* limestone, and *Shell limestone*, or *Muschelkalk*.

Others have local names given them, as the *Calcaire grossier* of Paris, a coarse limestone, some beds of which are used for building, while others are a mass of broken shells.

Cipolino is a granular limestone containing mica ; *Majolica*, a white, compact limestone ; *Scaglia*, a red limestone in the Alps.—(Murchison and Nicol, in *Johnston's Physical Atlas.*)

Ireland especially abounds in a great variety of limestones used for ornamental marbles, such as the green serpentine-marble of Ballynahinch in Galway, the black marble of Kilkenny, the brown, red, and dove-coloured marble of Cork and Armagh ; and many others less known, and some of them unworked, but equally beautiful, with those that are. In Derbyshire and North Staffordshire, we have a similar abundance of ornamental marbles.

Fresh-water limestones have commonly a peculiarity of aspect, from which their origin may sometimes be suspected, even before examining their palæontological contents, or petrological relations. They are generally of a very smooth texture, and either dull white or pale gray, their fracture only slightly conchoidal, rarely splintery, but often soft and earthy.

Travertine when massive, is generally of a yellow or brown colour, and a smooth and compact texture, but is sometimes perfectly crystalline. It is often mottled with concentric spheroidal bands of colour, from an inch to several feet in diameter.

Stalactites and *Stalagmites* are usually white or pale yellow in colour, but sometimes of a darker yellow or brown colour. They are commonly wrinkled externally in little ridges, taking the form of the water that trickled over the surface ; internally they exhibit concentric coats due to the method of their gradual deposition by successive films. It often happens, however, that radiating crystalline fibres, or even crystals half inch in diameter traverse many of these films without obliterating them, so that the whole has become perfectly crystalline internally, subsequently to the formation of the concentric coats, and while yet additional concentric coats are being added externally.

Flint and Chert.—The association of flints with Chalk is well known. Chalk flints occur as rounded nodular masses, of very irregular, and sometimes fantastic shape, and of all sizes, up to a foot in diameter. They are commonly white outside, but internally are of various shades of black or brown, sometimes passing into white. They have sometimes concentric bands of black and white colours internally, and exhibit markings derived from organic bodies round which they have often been formed. Flint occurs in the Chalk not only in nodules, but

also in seams or layers, sometimes short and irregular, sometimes regular, over a distance of several yards. These seams vary from half an inch to two inches in thickness, and are commonly black in colour.

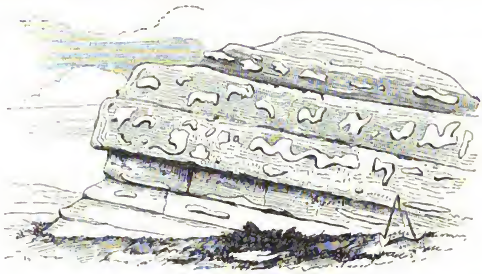


Fig. 7.

Sketch of some beds of limestone containing nodules of white chert, at Middleton Moor, in Derbyshire, in which the irregular and fantastic shapes assumed by these nodules are well exhibited, as also their likeness to flints in the Chalk.

Almost all large masses of limestone have their flints or siliceous concretions. These are frequently called *chert*, as in the Carboniferous limestone, where the nodules and layers of chert exactly resemble the flints in the Chalk.

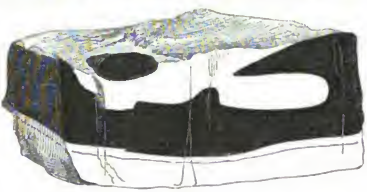


Fig. 8.

Part of a seam of black chert in the limestone near Dublin. These seams, like those in chalk, are sometimes quite regular for some distance, and then either suddenly terminate, split up, or are subject to other irregularities like those in the figure.

Even the tertiary limestones around Paris have their flints, the menilite of that locality being nothing but a siliceous concretion, found in the Calcaire St. Ouen, and possibly other places.

Pure siliceous concretions occur even in the fresh-water limestones and gypsum beds of Montmartre.

Siliceous Limestone.—The silica diffused through the calcareous mud, of which the limestone was composed, has sometimes remained so diffused, instead of separating as nodules or layers, producing a *cherty* or *siliceous limestone.*

Argillaceous Limestone.—Clay, or argillaceous matter, has frequently

been deposited with the calcareous, producing *argillaceous limestone*, which may be known by the earthy odour given out by it when breathed upon.

When the argillaceous has been mingled with the calcareous matter in very large proportion, a subsequent separation of the two has often taken place, the lime having segregated itself from the mass in this case, as the siliceous separated from the calcareous matter in the case of flints and chert. Nodular lumps of limestone are then produced, divided from each other by little, often irregular, seams and layers of shale or clay. These concretionary lumps of limestone are sometimes merely scattered through the clay, but they often form regular seams or beds, the upper, or under, or both surfaces being uneven and nodular.

It is sometimes difficult to say whether the little parting films and small seams of clay which occur between the beds have been deposited at different times from the calcareous matter, or, having fallen together with it as an argillo-calcareous mud, have had their calcareous particles sucked out of them, as it were, by the segregating influence of chemical affinity. It is by no means intended to infer that alternate deposits of thin layers of calcareous matter and purely argillaceous or arenaceous matter have not frequently occurred; we only wish to put the student on his guard against particular structures as proofs of original deposit, which, especially in so active and unstable a substance as carbonate of lime, may in many instances be the result of subsequent agency.

Hydraulic Limestone.—Limestone containing a considerable proportion of silica and alumina forms a mortar that sets under water, and is, therefore, called *hydraulic lime*. The limestone from which Parker's cement is formed contains carbonate of lime, 62 per cent; carbonate of iron, 6; silica, 15; alumina, 5; water, 6 per cent, and some oxide of iron.—(*Penny Cyclopædia, article Mortar.*)

Carbonaceous or Bituminous Limestone.—Carbonaceous matter, derived either from decaying vegetables, or perhaps more frequently from the decomposing animals of whose hard parts the rock is composed, produces in like manner the *black limestones*, which are in some instances called *bituminous limestones*. Little nests of pure anthracite, or other variety of carbonaceous matter, are sometimes found in the hollows of shells buried in limestone.

Fetid Limestone or Stinkstein.—The fetid smell, like that of sulphuretted hydrogen gas, given off by many limestones when struck with a hammer, is probably another result of the decomposition of animal matter, producing what is called "*fetid limestone*," or, by the Germans, "*stinkstein*." Some of the limestone quarries in the Carboniferous limestone of Ireland may be smelt at a distance of a hundred yards when the men are at work.

Arenaceous Limestone or Cornstone.—Calcareous sandstone was de-

scribed in the preceding chapter, and an arenaceous limestone is very much the same thing. Sometimes, however, the calcareous matter predominates so largely over the arenaceous that the rock is fairly entitled to the name of a limestone. Some *cornstones* are quarried and burnt for lime, not differing in composition from a slightly siliceous-looking limestone, and being either compact or semi-crystalline in texture.

Conglomeritic Limestone.—Some limestones contain angular or rounded fragments of other rocks, and thus become a conglomerate.

In the county of Dublin, some of the limestones belonging to the Carboniferous formation contain fragments of trap, grit, or slate, varying in size from a mere sand up to blocks of eighteen inches in diameter, and in quantity from a few dispersed pieces scattered through the limestone till they become a mere conglomerate of other materials, cemented by an almost invisible paste of calcareous matter.

In the county Limerick we find, in like manner, gradations from pure limestone, containing a few chips of trap and ash or a few layers of trappean sand, up to a calcareous brecciated ash, consisting of such a mixture of calcareous and trappean materials that it is difficult sometimes to say whether any particular bed should be called a limestone or a trappean ash.

In other parts of the county Dublin from those above mentioned, and in the more immediate neighbourhood of the granite hills, the limestone contains fragments of granite varying in the same way as regards size and shape, but frequently quite angular, and several inches in diameter. These were first described by Dr. Lentaigne in a paper read before the Royal Dublin Society in 1851, and a number of specimens were sent by him to the Great Exhibition in London of that year. They were subsequently brought before the notice of the Geological Society, Dublin, by Professor Haughton. Flat slabs of mica schist have since been found embedded in the limestone of Milltown, near Dublin, by Mr. Carroll and others.

These unrounded fragments of granite and mica schist may have been derived from the waste of pinnacles of the rock forming islets in the sea in which the limestone was deposited, or they may in some cases have been floated in the roots of trees and other vegetables, just as in the present day pebbles of hard stone, highly valued by the natives, are found in the roots of trees cast up upon the shore of archipelagoes of coral islands in the Pacific, as mentioned by Chamisso and Darwin.

Mr. Godwin Austen has described the occurrence of a boulder of Scandinavian granite, with sand and a pebble of greenstone, in the Chalk near Croyden, which he believes were transported by ice from northern latitudes.—(*Q. J. Geol. Soc.*, vol. xiv., p. 252).

Rottenstone.—Wherever a siliceous limestone is weathered or decomposed by the action of the atmosphere, and the calcareous part removed, the siliceous skeleton of the rock is left, producing what is known as rottenstone.

In arenaceous limestones, or calcareous sandstones or ashes, a similar dark coloured, more or less rotten rock is left by the weathering out and removal of the calcareous matter.

Magnesian Limestone.—Carbonate of magnesia is often found in marine limestones, mingled in various proportions with the carbonate of lime. Its occurrence in small quantity frequently gives a sandy appearance and gritty feel to an otherwise smooth and compact limestone.

In a true magnesian limestone or dolomite, the crystallization and the pearly lustre is generally very distinct, though sometimes the crystals are minute. Its colour is commonly some shade of brown or yellow, occasionally tinged with red; white, gray, or black varieties, however, occur sometimes over very large areas. Dolomite is frequently full of cavities from the size of walnuts up to that of a man's head, and these are often coated* with crystals of bitter spar. Dolomite is often quite disintegrated, and looks like a mere sand; but when examined by the lens, this apparent sand is found to consist of little detached crystals.

Magnesian limestone is very variable in lithological character. It is sometimes of a powdery, earthy, and friable texture; sometimes splits into thin slabs, some of which are flexible; sometimes forms singular concretionary masses, a number of balls touching each other, either like bunches of grapes, when it is called botryoidal, or like musket balls, or great piles of cannon shot. Many of these balls, on being broken open, are found to have a radiated structure. That all these curious forms have been produced subsequently to the deposition of the mass, is shewn by the fact of the lines of deposition or stratification proceeding through them regularly, without regard to the spherical outlines or radiated structure of the balls.

Magnesian limestone occurs in two forms, original and metamorphic. In some limestones, the carbonate of magnesia has clearly been deposited together with the carbonate of lime, the whole having been originally formed as a magnesian limestone.†

In other instances, it can be shewn, from the geological conditions, that whether the rock originally contained magnesia or not, its present distribution and mode of occurrence, and its highly crystalline structure,

* Any cavity in any rock lined with crystals of any substance is called a *drusy* cavity.

† Mr. Sterry Hunt has some valuable observations on dolomite in the Reports of the progress of the geological survey of Canada for the years 1857 and 1858. He shews that, in lakes, or in detached seas having no outlet, the deposition of gypsum and bicarbonate of magnesia may readily take place as the result of the mutual decomposition of bicarbonate of lime and sulphate of magnesia.

are the result of agencies operating subsequently to the original formation of the rock, and affecting a number of different beds simultaneously, along certain narrow lines of fissure, to the neighbourhood of which the *dolomitized* condition of the rock is confined. These veins or dyke-like masses of dolomite sometimes look like trap dykes running through beds of ordinary limestone.

57. *Gypsum* occurs as a rock in various ways. It sometimes forms regular beds, sometimes irregular concretionary masses, sometimes veins and strings in the mass of other rocks.

Compact Gypsum or *Alabaster** is one variety; granular, finely crystalline gypsum another. The thin beds and the veins and strings of gypsum are commonly fibrous, the fibres being at right angles to the beds. The gypsum of Montmartre, from which plaster of Paris is derived, is chiefly granular gypsum, each bed being composed of many layers of little crystals, slightly differing in colour and texture, and thus assuming a regularly laminated appearance. This would lead us to suppose that this rock, which is associated with fresh-water limestones and marls, was formed by the periodical deposition of layers of small crystals of sulphate of lime at the bottom of the water.

In August 1855, I observed in the quarries north of Montmartre one or two beds, six or eight inches in thickness, of beautifully crystallized sulphate of lime, in large perpendicular plates, interstratified with these little layers of crystals. All the beds were horizontal; and the layers of small crystalline grains were quite parallel to the stratification; but in the beds above mentioned, large tabular crystals and broad flakes of selenite, of rather irregular form, had struck directly across the bed, more or less nearly at right angles to it, the original horizontal lamination not being obliterated, but being in some places waved, as if slightly disturbed by the formation of the crystalline plates,

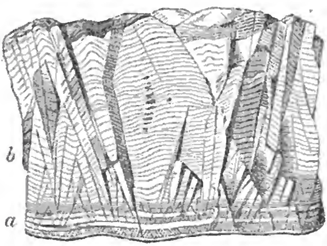


Fig. 9.

a, Layers of small crystalline grannles of gypsum.
b, Crystalline plates of gypsum, traversed by the faintly seen and displaced original layers of granules. These lines are not sufficiently oblique in the woodcut; on the faces of some of the crystals they form angles of 35° with the plane of the beds.

* Alabaster is so named from Alabastron, a town of Egypt, where it was manufactured into boxes for ointment. The term "alabaster" was then applied to carbonate of lime, as well as sulphate of lime.

the angles of these waves having evident relation to the faces and angles of the superinduced crystalline plates.

This formed a good case of a molecular change of structure, having taken place in the mass of the rock subsequently to its formation, like that before mentioned as occurring in the spheroidal concretions of magnesian limestone, and in the structure of stalactites and the limestone of coral reefs. It yet remains for the chemist to explain to us the exact method of operation by which these changes are produced.

58. *Rock-salt* commonly occurs in Britain as a rudely crystalline, irregularly bedded mass, commonly stained of a dirty red by the mixture of ferruginous clay and other impurities. Perfect cubical and transparent crystals occasionally occur, and curious spheroidal bands, of a white colour, are sometimes observable in the roof of a salt mine. Bed-like masses of rock-salt are often 60 or 90 feet thick, thinning out probably in all directions, and thus taking the form of large cakes. In other countries, more numerous beds occur, but not making up larger masses. In some of these, the salt is perfectly pure and white ; but in all countries, and in all geological formations, I believe I am correct in saying that the association of salt with gypsum, and with green, red, and variegated marls, is a frequent if not invariable occurrence. We have already seen how natural and almost inevitable is the occurrence of gypsum with rock-salt ; but the accompaniment of red and variegated clays has not yet been explained. When it is, it will probably throw great light on the circumstances under which the rock-salt itself has been deposited. Dolomite is also often found in connection with rock-salt.

59. *Coal* is a rock the general aspect and nature of which is familiar to everybody. Its chemical composition has been spoken of already, and its resemblance to that of wood, and the way in which wood might be converted into coal by a slight alteration in the proportion of its component parts, and an accompanying physical consolidation (see p. 140).

Coal is very commonly divided into bituminous and non-bituminous. Now bitumen is rather a vague term, including several combustible substances, such as asphalt or mineral pitch, elastic bitumen or mineral caoutchouc, naphtha, petroleum, etc. These bituminous substances are all either fluids, or are readily soluble in alcohol. It is, however, impossible to dissolve any appreciable portion of coal in alcohol, which shews that it does not contain any actual bitumen, though it may contain the constituents of it. The natural and artificial bitumens are the result of the decomposition of vegetable matter, and may be extracted also from coal by subjecting it to distillation. They always contain from 7 to 9½ per cent of hydrogen, combined with carbon and oxygen. The so-called bituminous coals, then, are those in which the mineralizing process has only proceeded to a certain extent, leaving a consider-

able proportionate amount of hydrogen and oxygen in their composition; while those called non-bituminous are those from which a greater quantity of the latter substances have been extracted, and a larger proportion of carbon left behind. If the decomposition of wood results in the formation of carbonic acid gas, which takes away both carbon and oxygen, or of carburetted hydrogen, which takes away a large proportion of carbon, the carbon in the remainder will not be in such excessive proportion, and the constituents of the resulting coal will more nearly resemble those of bitumen. In this sense they may be called bituminous coals. If, however, a large portion of the oxygen and hydrogen be extracted, either as water or in any other form, the proportion of carbon in the remainder becomes excessive compared with that in the composition of bitumen; and hence the coals may be called *non*-bituminous.

Coals vary greatly, not only in the proportions of their essential constituents,—carbon, hydrogen, and oxygen, but also in the amount of earthy matter (forming ash) which has been accidentally and mechanically mingled with those constituents. We have seen that the percentage of ash is sometimes as much as 35 per cent in coals that have been regularly analyzed. In poorer varieties of coal, however, such as are never brought to market, but which are occasionally used in particular localities, this percentage must be still greater; and we have in nature every gradation, from pure coal into a mere carbonaceous (commonly called bituminous) shale or "batt," which often contains enough inflammable matter to give out flame and support combustion for a time when burnt with better coals, but soon passes into a lump of ash, unaltered in form, and not retaining heat longer than a brickbat would under similar circumstances. These *batts*, shales, or slates, often accompany coal, being found not only either just above or just below it, but in it, in the form of thin seams, layers, or cakes, which are often not to be separated from it without some trouble.

Just as limestone is often mingled with clay, and passes through argillaceous limestone and calcareous clay (or marl) into clay itself, so coal passes through earthy or ashy coal, and carbonaceous shale, into common shale or clay, no very hard boundary line being to be drawn between the many minor graduating varieties of the different substances.

Discarding the impure or imperfect coals, the recognisable varieties of good coal are sufficiently numerous. They may be grouped under three heads,—anthracite, ordinary or pit coal, and brown coal or lignite.

Brown Coal or *Lignite* sometimes shews the structure of the plants from which it is derived but little altered from their original condition; stems with woody fibre "crossing each other in all directions. It is of

a more or less dark colour, soft and mellow in consistence when freshly quarried, but becoming brittle by exposure, the fracture following the direction of the fibre of the wood."—*Chemical Technology, Ronalds and Richardson*, vol. i., p. 32.)

"Other kinds present only occasional distinct indications of vegetable structure, and appear throughout as a stratified mass of a dark, nearly black colour, with an earthy fracture; while in some varieties the structure is still more dense, and the fracture is conchoidal." —(*Ib.*)

The latter varieties, as in the case of the Bovey coal of Devonshire, are often scarcely distinguishable by any external characters from some varieties of ordinary coal.

Ordinary or *Pit Coal* has many varieties; indeed, these are often as numerous as the different seams of a coal field, and even the different beds of a compound seam are readily distinguished from each other by the colliers, who give particular names to them; and even small blocks of these varieties can be recognised by them, and identified with the seam, or part of a seam, from which they are derived. Not only do the different beds of a compound seam present distinguishable varieties, but it sometimes happens, that the very same identical layer of coal changes its character and quality in different parts of its area. Neither are these distinctions, which are only to be perceived after long practice, unimportant, since these varieties have distinct qualities, some of them being better adapted to smelting, and said to be "good furnace coal;" some of them to blacksmiths' work, or "good shop coal;" others to various uses; while only a few, comparatively, are best fitted for domestic purposes, and are brought to market by the coal-merchant.*—

* I have entered a little more into detail on the subject of the extreme variation in the character of coal than I might otherwise have done, because it has lately assumed a practical importance. Legal trials, involving large sums of money, have taken place, as to whether a certain bed of coal in the Lanark coalfield, called "Boghead or Torbanehill coal," be entitled to be called coal or not.

Coal is a word in common use, not a scientific term invented to express a certain definite idea, or applicable only to a certain definite substance, and the common meaning attached to it ought, in my opinion, to be its legal meaning.

If coal be looked upon as a "mineral" in the strict scientific sense of that term, it should, of course, be capable of a definition, since a mineral has already been said to be a substance having "a definite chemical composition, and a certain definite form." It is, however, quite obvious that coal has neither the one nor the other of these, and therefore is not properly a "mineral." Hence the difficulties met with by a number of chemists and mineralogists in their attempts to treat the Boghead coal as a mineral, either chemically or by the physical characters of colour of streak, hardness, specific gravity, lustre, and so on.

If, on the other hand, we look on coal as a rock, which is the true method of regarding it, we are at once relieved from the necessity of attempting to define an indefinite substance, and prepared to admit as many gradations of variety in it as there are in sandstones, limestones, or clays.

Any stratified rock that would burn, that is to say, one of which a fire could be made and kept up without the addition of any other substance, would be as fairly entitled to be

(See Memoirs of Geol. Survey, South Staffordshire Coalfield, 2d edition, p. 18.)

Some idea of the number of varieties of coal may be gained from an inspection of the report of the Admiralty Coal Investigation (*Mems. Geolog. Survey*, vol. i.), as well as from the varying qualities of those which we are in the habit of using daily in our houses. "As many as seventy denominations of coal are said to be imported into London alone."—(*Chem. Tech.*)

All these minute varieties are commonly included under four principal heads :—1, Caking coal ; 2, Splint or hard coal ; 3, Cherry or soft coal, and 4, Cannel or parrot coal.

Caking Coal is so named from its fusing or running together on the fire, so as to form clinkers, requiring frequent stirring to prevent the whole mass being welded together. It breaks commonly into small fragments with a short uneven fracture. The Newcastle coal, and many others from different localities, are caking coals. They leave many cinders and a dark dirty ash.

Splint or Hard Coal is well known in the Glasgow coal field. It is not easily broken, nor is it easily kindled, though when lighted it affords a clear lasting fire. It can be got in much larger blocks than the caking coals.

" *Cherry or Soft Coal* is an abundant and beautiful variety, velvet black in colour, with a slight intermixture of grey. It has a splendid or shining resinous lustre, does not cake when heated, has a clear shaly fracture, is easily frangible, and readily catches fire."—(*Chem. Tech.*) It leaves comparatively few cinders, and its ash is white and light. It requires little stirring, and gives out a cheerful flame and heat. The Staffordshire coals principally belong to this variety.

Cannel or Parrot Coal is called cannel from its burning with a clear flame like a candle, and parrot in Scotland from its crackling or chattering when burnt. Cannel coal varies much in appearance, from a dull earthy to a brilliant shiny and waxy lustre. It is always compact, and does not soil the fingers. Its fracture is sometimes shaly, some-

called coal by the geologists, as it would by people in general ; and neither chemist, mineralogist, nor microscopist, nor any other persons, would be entitled to say that it was not coal, because it might not happen to come within the limits of any definition it may please them to frame for coal.

A geologist is as fairly entitled to be an authority as regards rocks, as a botanist with respect to plants, a zoologist with respect to animals, or a mineralogist with respect to minerals. The geologist is quite right in appealing for information to each of the above-named classes, and all of them to the chemist, but when the person applied to has given that information, he is not warranted in usurping the authority of the applicant, and dictating to him as to the use which he may make of the information afforded, or limiting his judgment upon it.

Even if it could be shewn that the Boghead coal was formed from a clay impregnated with bitumen, that would not prove that it was not coal, it would merely shew that there were more ways of forming coal than we had previously been aware of.

times compact. The bright shining varieties often burn away like wood, leaving scarcely any cinders and only a little white ash. The duller and more earthy kinds leave a white ash, retaining nearly the same size and shape as the original lumps of coal. Cannel coal often takes a good polish, and can be worked into boxes and other articles.

Jet is an extreme variety of cannel coal in one direction, as *batt* or carbonaceous shale is in another.

Anthracite is heavier than common coal, with a glossy, often irridescent lustre, and a more completely mineralized appearance. It rarely soils the fingers, has a distinctly sharp-edged conchoidal fracture, or else breaks readily into small cubical lumps. It is not easily ignited, but when burning gives out an intense heat, so as to sometimes melt the bars of the grate or furnace in which it is used. It does not flame, and gives off but little smoke, being in this respect similar to coke or charcoal.

In many ordinary coals, little flakes of mineral charcoal occur, retaining that part of the vegetable structure called the vascular tissue. They are called "mother of coal" by the colliers in some places. "It is frequently seen in the form of a thin silky coating, covering some of the surfaces of the coal."—(Professor Harkness on Coal, *Edinburgh New Philosophical Journal*, July 1854.) Microscopical examination exhibits not only the vascular but the cellular tissue of plants in the substance of many coals, as was shewn by Mr. Witham in his work on the structure of fossil plants, and by many observers since.

The Face or Cleet of Coal.—Most coals have a peculiar structure, which bears a slight analogy to the crystallization of a mineral. They break or split not only along the bedding, but across it, along two set of planes at right angles to the bedding and to each other. The smooth clean faces produced by one of these planes are more marked and regular than that produced by the other, as may be seen by examining any lump of coal. The principal of these division planes are called by the colliers the *face* of the coal, the other being called the *back* or *end* of the coal. They preserve their parallelism sometimes over very wide areas; and the mode of working or getting the coal, and the direction of the galleries, is governed by the direction of the *face*. It is a structure which is probably the result of the mineralizing process undergone in passing from an organic to an inorganic state, or rather perhaps from an incoherent to a consolidated condition, and is one case of the "joint" structure of rocks, under which head it will be spoken of hereafter.

CHAPTER VII.

AERIAL ROCKS.

ALTHOUGH the amount of rocks, or accumulations of earthy matter, formed of materials which were brought into their present situation by the action of the wind, is comparatively of small importance, it is not expedient wholly to overlook this action. Along all low sandy coasts, hills are formed of drift sand, which sometimes attain a considerable altitude, as much, for instance, as 200 or 300 feet. These hills are commonly called "dunes." They have been described as advancing on the low shores of France, in the Bay of Biscay, at the rate of sixty and seventy feet per annum, overwhelming houses and farms in their progress.* Similar accumulations take place on the coast of Cornwall, where the sand, composed largely of fragments of shells and corals, becomes converted sometimes into a hard stone by carbonate of lime or oxide of iron.—(*De la Beche's Manual.*)

Lieut. Nelson has described similar aerial accumulations in the Bermuda Islands, giving them the name of æolian rocks.

Along the south coast of Wexford, as also in Smerwick harbour (county Kerry), and other parts of the British Islands, similar accumulations are in progress.

On the eastern coast of Australia, about Sandy Cape, this process is going on on a still larger scale. In Port Bowen, in the same neighbourhood, I once saw a very good instance of it. The rise and fall of tide there is as much as sixteen feet; and, at low water, great sandbanks are exposed, derived from the shallow sea outside, and the waste of the porphyritic rocks on the coast. These sandbanks rapidly dry under the hot sun; and the trade-wind, which blows home upon the shore, then drifts the sand up upon the beach, and piles it into hills 50 or 60 feet high. Behind these hills is a large mangrove swamp, which is being gradually buried under the advancing sand, some of the mangrove trees only just peering above it, others half covered, and so on. The drift of sand through the gaps of these dunes

* This progress has within the last quarter of a century been arrested by the planting of pine forests, the turpentine of which has become the source of a large revenue.

was exactly like a snow-drift in a heavy storm whenever the wind blew freshly.

Large districts, with hills of 200 or 300 feet in height, are found also on the coasts of Western Australia, stretching sometimes ten miles inland, formed of loose incoherent sand, once apparently drifted by the wind, though now brought to rest by the growth of a wide-spread forest of gum-trees. Parts of these sands, which consist greatly of grains of shells and corals, are compacted together into a stone, hard enough to be used for building, by the action of the rain-water dissolving some of the carbonate of lime, and re-depositing it on evaporation. Curious cylindrical stems, from one inch to eighteen inches in diameter, are there seen projecting from the soil, and have been taken for petrified trees, which they greatly resemble; but I observed, in 1842, a number of these supposed trees exposed in a little cove, south of the entrance of Swan River, ending downwards in tapering forms like stalactites; and I believe them, therefore, to have a stalactitic origin, due to the percolation of water down particular pipes and channels in the sand.

Nor is it along the coast only that such accumulations are taking place. In the interior of great dry continents, there are vast spaces covered with sand and sand-hills, which are shifted and carried about by the wind, just as some sandbanks are deposited now here now there, carried about by the water. We have but to recall to the mind of the reader the well-known stories of caravans crossing the desert, being met and sometimes overwhelmed by moving columns of sand, and the way in which many of the temples of Egypt have been buried under such accumulations, for him to see that this action cannot be altogether overlooked. Egypt would probably have been long ago obliterated by drift-sand if it had not been for the Nile, and the strip of vegetation that accompanies and defends it. In the interior of Australia, Captain Sturt reports the existence of vast deserts of sand, with long lines of great sand-hills, 200 feet high, the base of one touching that of its neighbours, and all stretching in straight lines each way to the horizon.

It would be quite proper also to class among aerial rocks such accumulations of tuff as were derived from volcanic ashes falling on the land, and also the masses of pebbles, cinders, and fragments so derived, were it not more convenient to describe them in connection with the volcanic rocks, so as not to separate in our account those falling on the land from those deposited in water.

Soil.—The accumulation of decayed vegetable matter, mingled sometimes with animal, always with earthy mineral matter, which is called "soil" or "mould," is also an aerial process, deserving of more attention than it has yet received. Soils sometimes occur as distinct rocks, interstratified with other rocks.

CHAPTER VIII.

THE METAMORPHIC ROCKS.

Preliminary Observations.

Concretions.—The segregation, into concretionary lumps and nodules, of siliceous from calcareous matter, and of calcareous from argillaceous, has been already described, and the radiated and concretionary forms assumed sometimes by magnesian limestone subsequently to its deposition, and the superinduced crystalline structure across the concentric coats of stalactites and the layers of granular gypsum. These, however, are not the only instances of such separation of parts, and assumption of new forms and combinations, by the particles of rock after their deposition, and after their more or less complete consolidation. Any mineral diffused in a state of minute division through a mass of different nature from itself, seems to have a tendency to segregate itself from the mass, and collect together upon certain points or centres. Iron, either in the form of iron pyrites (bi-sulphide of iron), or ironstone (clayey carbonate of iron, or hæmatite (oxide of iron), frequently forms such concretionary lumps. Iron pyrites, either in cubical crystals, or in balls with an internal radiated structure, is frequent in all argillaceous and calcareous rocks, and in many trap rocks.

Ironstone Balls and Septaria.—Ironstone forms regular layers of round nodules, sometimes as much as a foot or eighteen inches in diameter, in many argillaceous rocks. These nodules, when broken open, are often found to be traversed by cracks in all directions, more or less filled up with crystalline spar (carbonate of lime, etc.), together with crystals of galena, blende, iron pyrites, and other minerals.

In other clays carbonate of lime, mingled perhaps with iron, produces similar stones, called *Septaria* or cement stones. They often take a polish, and the sparry veins produce a pattern, which causes them to be used for marble tables or similar purposes.

In these septaria and ironstone balls the external crust is generally smooth and compact, the internal cracks becoming larger and more numerous as they proceed towards the centre. As the cracks are obviously the result of desiccation and consequent contraction, and as

the external crust would naturally be the first part to consolidate, it does not at first seem obvious why the cracks should not occur outside rather than in.

Professor Hennessey, however, remarked to me, that in the case of volcanic bombs, which have a similar structure, the fact of the preliminary consolidation of the external crust was the cause of the internal fissuring, since, when the crust was formed, no farther shrinking or contraction of the whole body could take place ; and the internal parts being thus relieved from external pressure, would shrink and contract among themselves, being rather attracted towards the dense external crust than towards the centre. If consolidation commenced at the centre, the whole nodule would have contracted towards the centre, and thus have shrunk into a less size and a denser state, without the occurrence probably of either external or internal cracks.

Nodules.—Hæmatite, whether red or brown, affects a kidney-shaped concretionary form, often hollow, with a minutely radiated structure at right angles to the surface of the mass.

Other minerals, such as galena and blende (the sulphides of lead and zinc), occur in small balls or nests in some rocks, evidently formed as concretions, and not rolled fragments or pebbles.

Many shales decompose into large round nodules, sometimes two or three feet across, and these sometimes enclose other nodules, the lamination of the rock proceeding straight across them ; and many sandstones are marked by concentric bands of colour.

Metamorphic Actions.—This assumption of a condition more or less different from that possessed by rocks at the time of their original formation, leads us naturally to consider the next great division of our subject, the metamorphic or transformed rocks.

Pressure.—The merely physical force of pressure, as aqueous rocks after their formation become gradually covered by subsequent accumulations, must produce change in them in the way of consolidation and induration. This pressure will of itself be sufficient in some cases to cause the hitherto incoherent particles of sand or clay to cohere and be compacted into a solid stone. It will, however, be greatly assisted, either by the infiltration of water containing mineral matter in solution, or of pure water dissolving and re-arranging the soluble materials which it may find in the rocks.

Heat.—Heat may, in like manner, modify the effects of pressure, either by its mechanical power of expansion producing pressure in every direction, and subjecting rocks to alternate expansions and contractions according to its own variations, or by setting in action chemical forces of decomposition and recomposition, and thus altering the chemical combinations in the materials of rocks.

Heat and Water.—Heat may also be joined with water, either rais-

ing it to various temperatures or actually converting it into steam, and we may thus get changes produced which neither cold water nor dry heat would be able or likely to effect of themselves. It has been stated that it is impossible to maintain the bulb of a thermometer in the boiler of a steamer at very high temperatures, since the glass is dissolved by the chemical action of water heated under pressure.—(*Sedgwick's Introduction to Synopsis of Classification*, etc., 3d Fasciculus, p. 29, note).

Now, it may not unfrequently happen that we may have all the forces of pressure, heat, and the dissolving power of water combined in the interior of the earth.

The presence of water in rocks is known by experience, since no stone is ever quarried which will not part with some water on being dried, either naturally in the air or artificially. Bischof says, that he has observed, on breaking blocks of basalt, "wet patches, like rain drops, upon the fractures, and sometimes quite in the centre of the mass, affording positive evidence of the permeability even of so compact a rock as basalt." He says also, that almost all water contains both carbonic acid, and often a slight proportion of silica (silicic acid) in solution, that the silicates in which the silica is in its soluble modification are decomposed by weak acids, and that those also in which it is in its insoluble modifications are unable to resist the long continued action of acids.

Weathering of Rocks.—This gives us the explanation of the brown spots and patches found in many rocks containing silicate of lime, such as basalt and greenstone, and also their brown and weathered surfaces. Along the internal margin of the brown part of basalt and greenstone a mineral acid will almost always cause effervescence, as also along the minute cracks and crevices and pores by which the water gains access to the interior. It is plain that the silicate of lime is converted into carbonate in the first place, and this being removed by subsequent solution from more carbonic acid, the protoxide of iron left behind is converted into peroxide, and the brown colour produced.

Limestone containing much silica or silicate of alumina, and some protoxide of iron diffused through its mass, is, in a similar way, converted into *rotten stone*, while pure limestone is wholly dissolved and washed away.

The decomposition of those rocks which do not contain any lime proceeds in the same way, though it is not so easy to detect it by the occurrence of effervescence with acids along the margin of the decomposed part. Feldspar rocks have their silicates of potash, soda, etc., converted first into carbonates and then into bi-carbonates, which are dissolved and washed away. Their decomposed portions are generally white rather than brown, from the absence of iron, though shades or

streaks of red and brown occasionally occur, shewing its presence in small quantities.

Formation of Pseudomorphs.—In the examination of these changes, the study of pseudomorphic crystals of minerals is of great importance. A pseudomorph is one mineral occurring in the crystalline form of another. They are either "alteration pseudomorphs," in which the first mineral has been gradually changed into the other, or "displacement pseudomorphs," in which the first mineral having been gradually removed particle by particle, another has gradually, and particle by particle, taken its place. This action is a very important one, for it is precisely that of "petrifaction," as it is called—that by which organic remains are mineralized, and their external form, and more or less of their internal structure, preserved.

Petrifaction.—Animals and plants, by means of their fluids, take up and convert into their own substance certain minerals, such as silica, lime, magnesia, soda, potash, phosphorus, carbon, iron, etc. This they do in obedience to the organic forces, those chemico-biological actions, the assemblage of which we call *life*. When life no longer exists, and its forces cease to act, the substances of animals and plants become obedient to inorganic laws, and their mineral portions are acted on just in the same way that other mineral matters are affected. Wood may either, as we have already seen, lose certain *proportions* of its constituents and become more and more *carbonized;* or it may lose the whole of them particle by particle, and as each little molecule is removed, its place may be taken by a little molecule of another substance, as silica, or iron pyrites, and it may thus become entirely *silicified* or *pyritized.*

Bones and shells, and other hard parts of animals, consisting mainly of phosphate and carbonate of lime, may, in like manner, have the proportions or the state of aggregation of their constituents altered more or less completely, or may have their substance gradually but entirely replaced by another substance more or less different from the former.

In this way parts consisting originally of carbonate of lime may either have the organic cellular structure obliterated by assuming a crystalline structure, or may become embedded in a crystalline covering of carbonate of lime, or that mineral may be converted into sulphate of lime or replaced by silica, iron pyrites, or other substances, the cellular structure being in each case either preserved, or partially or entirely obliterated.

Method of Pseudomorphic Action.—Bischof combats the opinion that this pseudomorphic and petrifactive process is ever the result of dry heat or of sublimation, and shews, with what appears conclusive reasoning, with regard to many substances at all events, that whether it occur in the mass of rocks, or in veins and fissures, it must be the

result of *water* (temperature uncertain) containing some acid, chiefly carbonic acid, in solution in the first place, and afterwards by means of that acid becoming impregnated with the solutions of other minerals.

Some of Bischof's remarks are so very instructive that we do not hesitate to quote several passages at length. "Stein converted a crystal of gypsum into carbonate of lime by leaving it for several weeks in contact with a solution of carbonate of soda, at a temperature of 122 F." The sulphuric acid of the gypsum united with the soda to form sulphate of soda, which was dissolved and carried away by the water, and the lime united with the carbonic acid. "All the striæ upon the curved surfaces of the crystal were perfectly retained, as well as the cleavage in the direction of the T-planes. In these artificial pseudomorphic processes, the form of the original substance is retained only under certain conditions, the most essential being slow action ; and the same holds good in nature. If these conditions are not fulfilled, the original form is lost."

"In the analysis of a mineral in which changes have already commenced, especially by the addition of new constituents in very minute quantities, it is not unlikely that they may be considered as accidental and deducted. Since, however, alterations seldom take place merely by addition, but more frequently by loss of constituents, it is likewise requisite that the quantities lost should be added to the analytical results.

"There are sufficient grounds for considering andalusite to be a pure silicate of alumina, although previous analyses have pointed out, besides these two essential constituents, potash, lime, magnesia, oxides of iron and manganese, and water. Andalusite is converted into mica, in which change a part of the alumina is removed ; potash, magnesia, and peroxide of iron, being introduced into its place. One of these bases is always found in andalusite, sometimes several of them together ; and it may therefore be inferred that this mineral, as usually met with, is already in a state of incipient alteration. No other alteration of andalusite is known besides that into mica, except that into steatite. The latter change presupposes not only a partial but a complete disappearance of the alumina, and its replacement by magnesia. These examples will suffice to shew the importance of the minute quantities of substances present in minerals, and generally considered as accidental. These substances, which are troublesome to the chemist, because he cannot introduce them into the chemical formula, acquire significance when compared with the constituents of the pseudomorphs resulting from the alteration of the mineral in question. They then no longer appear as accidental, but indicate the transition of one mineral into others, and lay before us clearly the greater part of the conversion process.

"It is possible that several changes may frequently have taken place before the last product was formed. In the alterations of complex minerals, especially silicates containing several bases, there are certainly transitions in most cases, and sometimes a long series. Thus Cordierite* is the starting point of a whole series of alterations, finally ending with Mica; while Fahlunite, Chlorophyllite, Bonsdorfite, Esmarkite, Weissite, Praseolite, Gigantolite, and Pinite, are remains of Cordierite in pseudomorphic conditions. Inasmuch as the minerals between Cordierite and Mica are only transition products, they cannot be regarded as individual species."† "As petrifactions are important, and in many cases indispensable aids in recognising the sedimentary formations, so likewise pseudomorphs are important, and frequently the only means of tracing the processes of alteration and displacement which have taken place and are still going on in the mineral kingdom.

"Pseudomorphs furnish us with a kind of knowledge which we have no opportunity of deriving from any other source. It will scarcely ever be possible to convert augite, olivine, or hornblende, etc., into serpentine in our laboratories. But when we find serpentine in the form of these minerals, this fact is a sufficient evidence that such a conversion can take place; and if in any given instance there are geognostic reasons for the opinion that one or other of these minerals, or even several together, have furnished the materials for the formation of serpentine, there is a high degree of probability that such a change has actually taken place.

"If a crystalline mineral can, under certain conditions, be converted into another, whether with or without retention of form, then the same mineral in an amorphous state would certainly suffer the same change when placed in the same circumstances." From this he shews that amorphous masses of serpentine may be formed from amorphous masses of augite, etc., and also that in some instances the original form of a crystalline mineral may be destroyed together with its substance, and the new mineral occur in its own crystalline form. He concludes the subject thus:—

"The importance of the pseudomorphic processes, and the error of those who regard them as having but little connection with the changes of rocks, is sufficiently shewn by the total disappearance of previously existing substances in veins. I consider that the entire removal of fluor and calc spar from a whole series of veins, and the introduction of an

* Cordierite is a mineral composed of a silicate of alumina, combined with two atoms of silicate of magnesia.

† If farther well-considered researches establish these and similar conclusions, it will have a wonderful effect in simplifying the important science of mineralogy, and thus give a greater attraction to a subject which has, on my mind at least, always exercised a most repulsive action, from the want of a clear, simple, and definite rule of classification.

equal quantity of quartz in their place, is a matter of vast importance. To what enormous spaces of time do we come when we reflect upon the periods during which the fluor and calc spar were introduced into these fissures, and then the periods during which they were again removed by water, and quartz substituted in their place! And yet this happened after the formation of the rocks in which these fissures occur. If we imagine similar processes to have taken place in the rocks themselves, and extending over not only both these periods, but the entire space of time since their formation, we shall be compelled to admit that inconceivably stupendous changes have taken place. After such considerations, the conversion of extensive masses of rock by the action of water alone into steatite, talc, serpentine, kaolin, etc., cannot appear in the slightest degree strange."—(*Bischof*, chap. ii.)

Metamorphosis by Water at Ordinary Temperature.—If we allow so large an amount of metamorphic action to the infiltration of water, it becomes no longer difficult to understand the conversion of limestone into dolomite, subsequently to the deposition of the original carbonate of lime. Such cases as those described by Von Buch, and more recently by Mr. Andrew Wyley, in the Journal of the Geological Society of Dublin (vol. vi., part 2), in his paper on the dolomitic rocks of Kilkenny, where dolomite is found traversing ordinary limestones in dyke-like masses running through a great number of beds in a straight line across the country, become explicable on the supposition of springs of water containing much carbonic acid and magnesia rising up through fissures, and the consequent solution of some of the carbonate of lime, and its removal in a dissolved form, and its replacement by carbonate of magnesia (see sheets 147 and 157 of Map of Geol. Sur. of Ireland, and their Explanation).

Metamorphosis by Hot Water or Steam.—If, again, such great changes as those just alluded to may be expected to result from the simple action of water, we may reasonably conclude still greater to be the consequence of the action of water combined with a high temperature, or of a still more intense heat, which first converts into steam the water contained in rocks, and effects great changes perhaps, or, at all events, prepares the way for great changes by that agent, and then proceeds to act upon the minerals contained in rocks with its own powers. We have already seen that some sandstones and gritstones may have probably been cemented by silica held in solution, either in the water in which they were deposited, or in that which subsequently gained access to them. We know that hot water can contain at least a tenth more silica in solution than cold water. If, therefore, a sandstone became penetrated by hot water, or still more by steam, a portion of the silica of which each grain was composed might be dissolved, and as the water ultimately evaporated, this silica would be re-deposited, and

act as a siliceous cement to the mass. We should thus have a quartz rock or quartzite produced.

Metamorphosis by Dry Heat.—It would appear, however, that dry heat alone is able, under favourable conditions, to produce this effect, since the sandstones that have been used as the bottoms of iron furnaces are, in some cases, altered into a kind of quartz rock. It is true that bases, calculated to act as a flux to the quartz, may have gained access to the sandstone in the latter instance, but then they may, on the other hand, have been present in sufficient quantity for that purpose in many sandstones that have been naturally altered into quartz rock.

Metamorphosis by Heat, whether with or without Water.—Bischof and some other continental writers seem still to be imbued with what I must look upon as an old-fashioned prejudice against the notion of any metamorphic rocks having been produced by the action of heat. This retention of prejudice seems to me to arise partly from their want of an adequate conception of the vast action of denudation, and partly from an erroneous determination of what are and what are not true granitic rocks.

When we see whole mountain ranges, and whole districts of country, consisting of rocks that have more or less analogy in structure and constitution with rocks known to be of igneous origin, we cannot help feeling convinced that igneous action must in some way have been concerned in their production.

When we find that these rocks have almost every gradation, from such as we might imagine to have been once molten, into rocks which we know to have been mechanically deposited under water, we are compelled to conclude, with Lyell, that these rocks are altered or metamorphosed by heat, from their original aqueous and mechanical formation, into a state more or less nearly approaching that of true igneous rocks.

Our belief in the truth of this metamorphism becomes certainty when we see these rocks always occurring on the flanks of masses of granite, and examine a district (such as Wicklow and Wexford) where both large and small masses of granite appear, and find these metamorphic rocks not only always accompanying the granite, but occurring *no where else* except in the neighbourhood of granite, and their extent always proportioned to the size and extent of the particular granite mass they mantle round.

It is by no means intended to assert that the neighbourhood of granite or igneous rock is the only source of heat from which this metamorphosis can arise, since this is exactly one of the misconceptions alluded to above. Should any mass of rock, capable of alteration, be so deeply buried in the earth as to be brought within the reach of any centre of heat whatever, the same effect would result; and it is most

likely that a far greater intensity and wider range of heat may be thus reached than could proceed from the mere intrusion of a more or less isolated mass of igneous matter into spaces which were naturally of a lower temperature. But as an intrusive mass of granite must be a source of great heat, and as the metamorphic effects in question are found always to accompany it, it is a fair inference that heat is one of the necessary causes of the effect.

The presence or absence of water, either previously to the occurrence of a high temperature, or simultaneously with it, may doubtless be one of the modifying causes, producing some of the great varieties among a mass of metamorphic rocks; those varieties also depending very largely on the different materials, or the different proportions in the same materials, which existed in the different beds previously to the metamorphic action taking place.

While speaking of a high temperature, I by no means wish to limit its range in either direction. Mr. Sterry Hunt, in the Reports of the Geological Survey of Canada for the years 1853-6, argues, that from the occurrence of graphite or unoxidized carbon in the metamorphic schists of Canada, the heat could never have been very intense, or at all approached the melting point of the silicates. He shews that water at 212° F., containing solutions of alkaline carbonates, would be sufficient for the solution even of silica, and the decomposition of silicates and the formation of garnet, epidote, and chlorite, and other silicates of lime, magnesia, and iron, and that if the temperature be raised to 480° it might suffice for the production of chiastolite, staurolite, etc., and feldspathic and micaceous silicates generally. Such temperatures may readily be supposed to be imparted to portions of the earth's crust, either locally, by the intrusion of granite, as in the south-east of Ireland, or over wider areas, when any part of what may now be the surface was as deep as from 10,000 to 20,000 feet below the surface.

Frequent appearance of Mica.—The very general appearance of mica, either in distinct flakes or crystals, or as a mere glaze upon the surfaces of laminæ,* may perhaps be explained by the very various composition of the different varieties of mica, and the consequent number of sources and combinations from which micaceous minerals could be derived.

The metamorphic development of mica, then, offers no difficulties; and we may perhaps suppose that in mica schist, where there are sometimes alternate layers of mica and quartz, this development took place in such a way that the basic substances segregated themselves into alternate layers, leaving the silica of the intermediate layers free.

In gneiss, where we have the triple alternation of quartz, feldspar, and mica, a similar action similarly directed must be supposed to have

* See *postea*, under the head of Petrology, remarks on the production of mica schist and gneiss on the flanks of the granite of Wicklow, etc.

occurred under the modifying influence of a difference in the composition of the original rock.

We shall have occasion, under the head of petrology, to recur to this subject in describing the "cleavage" and "foliation" of the metamorphic rocks. "Cleavage" is, indeed, a purely petrological structure, whatever may have been its origin, since it rarely, and only to a slight extent, produces any lithological change in a rock beyond that of simple induration. A highly indurated *shale* has no lithological difference from a true *clay slate*, it being often impossible, from an inspection of a mere hand specimen, to say whether it be one or the other.

Description of the Metamorphic Rocks.

The metamorphic rocks may be divided into two sub-groups, those in which the original mineral structure is still recognisable—the particles, however they may have altered their form and state, not having entered into new combinations—and those where such new combinations have been produced.

The former sub-group will accordingly consist of arenaceous, argillaceous, and calcareous rocks, while the members of the latter have a general similarity of structure and composition which enables us to speak of them under one general term, such as the *schistose rocks*.

Metamorphosed Arenaceous Rocks.

60. *Quartz Rock or Quartzite** is a compact, fine-grained, but distinctly granular rock, very hard, frequently brittle, and often so divided by joints as to split in all directions into small angular but more or less cuboidal fragments. Its colours are generally some shade of yellow, passing occasionally into red, and at other times into green. When examined with a lens it may be seen to be made of grains, which appear sometimes as if they had been slightly fused together at their edges or surfaces, and sometimes as if embedded in a purely siliceous cement. This cementation or semi-fusion of the grains shews at once that it is a

* The student must carefully distinguish between quartz rock or quartzite, as here described, and pure *vein quartz*, which occurs sometimes, as a white compact flint rock, in considerable mass. The "quartz rock," so often spoken of in Australia, is rarely, if ever true quartz rock, but commonly vein-quartz; not an altered bed of sandstone contemporaneous with the rocks in which it lies, but a deposition in a vein or fissure produced subsequently to the consolidation of the rocks it traverses.

The Continental geologists seem frequently to fall into the same mistake, and confound two things essentially distinct. In a collection of European rocks purchased lately from Krantz of Bonn, among seven specimens of so-called quartzite, at least five were undoubtedly *vein quartz* and not *quartzite*.

sandstone which has been altered and indurated by the action either of heat alone or of heat and water. It has either been *baked* or *steam-boiled*.

Metamorphosed Argillaceous Rocks.

61. *Hornstone.*—Clay or shale has been in some cases, as in that of the Lias of Portrush, converted by contact with a large mass of Greenstone, into a smooth, hard, brittle, splintery rock, that might be called Hornstone. The fossils in the Hornstone of Portrush are still perfectly preserved, though the rock is so hard and unlike clay as to have been originally described as basalt, and adduced by the Wernerians as a proof of the aqueous deposition of basalt.

62. *Clay Slate* is a fine-grained fissile rock, differing from shale in being invariably highly indurated, and splitting into plates that are altogether independent of the original lamination or bedding of the rock, sometimes coinciding with it, but frequently crossing it at all angles. This fissile structure or "cleavage" is a superinduced metamorphic one. The original bedding or lamination of the rock may frequently be traced, even in hand specimens, by means of parallel lines or bands of different colour and texture traversing the slate. These bands are called by Professor Sedgwick the "stripe" of the slate.

Clay slate is generally of a dull blue, gray, green, or black colour, sometimes "striped," sometimes irregularly mottled.

Metamorphosed Calcareous Rocks.

63. *Altered Limestone.*—This was formerly called *Primitive*, and is even at the present day often called *Primary Limestone.* Since, however, it is known that many crystalline limestones are not Primary, that the statuary marbles of Italy and Greece, for instance, are some of them Secondary, and some even Tertiary limestones in a metamorphosed state, it would seem better to disuse the term *primary* as a mere lithological designation.

Some limestones were originally formed as crystalline limestones, just as many parts of a coral reef and some stalactites are crystalline internally. Others, however, have certainly been only made to assume the crystalline structure at a period subsequent to their formation. In the well-known experiments of Sir James Hall, it was shewn that even chalk could be converted into a hard crystalline marble, by being heated under such a pressure as should prevent the escape of the carbonic acid gas.

Saccharine or statuary marble is a white fine-grained rock resem-

bling loaf-sugar in colour and texture, working freely in any direction, not liable to splinter, slightly translucent, and capable of taking a polish. Concealed flakes of mica or chlorite sometimes exist in it, as may be seen on examining the weathered surfaces of some of the ancient statuary in the British Museum and elsewhere.

Other varieties of altered limestone are variously coloured, and more largely and coarsely crystalline.

64. *Dolomite.*—Many of the masses of dolomite which occur in limestone formations are certainly altered rocks, the original texture of the mass being often changed as well as its chemical composition.

These metamorphic dolomites are generally perfectly crystalline, either in large or small granules, and have often a porous texture, so that the crystalline granules can be seen to touch each other at only a few points. This causes them to be easily disintegrated, and fall into a kind of sand consisting of grains of Bitter spar. It is often more largely cellular, having drusy cavities lined, and sometimes filled, with large crystals of Bitter spar. The colours are generally yellowish-white, yellow, or brown, sometimes reddish.

There is, however, no good lithological distinction between dolomite which is the result of a metamorphic action upon ordinary limestone, and dolomite such as that of the magnesian limestone formation of the north-east of England, which it seems impossible to suppose was otherwise formed than as an original deposition of magnesian limestone.

65. *Serpentine.*—There are some rocks called Serpentine interstratified with highly metamorphosed rocks (like the serpentine marble of Ballynahinch, Galway), that I have long suspected may be merely the extreme metamorphic form of a siliceous magnesian limestone, the carbonates being converted into silicates.

Sir W. Logan, director of the geological survey of Canada, assured me that he had in that country traced serpentines which gradually passed into beds of unaltered magnesian limestone. Mr. Sterry Hunt describes the association of serpentines, or ophiolites and ophicalcite, in the Report of the Geological Survey of Canada for 1853 and 1856.

Serpentine, however, may doubtless be sometimes the result of the metamorphism of augitic or hornblendic rocks, or of the ashes of those rocks, their decomposition and degradation if they were traps, but their consolidation, and perhaps alteration by heat, if they were fine-grained or compact ash.

The Schistose Metamorphic Rocks.

The term "schist" is used here in a restricted sense, as applicable to the fissile structure of "foliated" rocks.

"Foliation" is a term applied by Mr. Darwin* to those rocks which have had such a subsequent structure given to them as to split into plates of different mineral matter, either with the bedding or across it. "Cleavage" indefinitely splits a rock, either with the beds or across them, without altering its mineral character, and thus produces "slate."

"Lamination" will then be the remaining term applicable to "shale," and signifying the splitting of a rock into the original layers of deposition.

When, therefore, we wish to be precise, we can speak of the *foliation* of *schist*, the *cleavage* of *slate*, and the *lamination* of *shale*.

66. *Mica Schist* consists of alternate layers of mica and quartz, the mica generally formed of a number of small flakes firmly compacted together, and the quartz more or less nearly resembling *vein* quartz. Many mica schists, however, contain comparatively little quartz, and seem scarcely to differ from clay slate or shale, except in the shining surfaces of their plates or folia, which look as if all the particles of which they were originally composed had been blended together so as to be no longer separable.

Mica schist has often a minutely corrugated or crumpled structure, the layers being bent into sharp vandykes of one, two, or more inches in height and width.

The separation into layers, or "foliation" of mica schist, sometimes coincides with the original bedding of the mass, and sometimes is independent of it. In the latter case, it may in some cases have taken the direction of a previously existing "cleavage."—(Prof. Ramsay, *Geological Journal*, vol. ix. p. 172.)

Many soft highly micaceous sandstones require only a little induration and blending of their particles to form "mica schist." In parts of the New Red sandstone of central England, the rock is so highly micaceous as to split into thin flags of a quarter of an inch in thickness and a foot in diameter; and these can be split by the nail into still finer flakes. The application of great or of long-continued heat would easily cause the peroxide of iron and the alumina present to form mica, in addition to that already existing, and the two might, perhaps, coalesce into layers, leaving the partially or entirely fused quartz grains of the sandstone in intermediate layers of quartz.

Instead of mica, other minerals are sometimes found, such as chlorite or talc, when the rock would be called *chloritic schist, or talcose schist.*

Hornblende Schist, again, occurs, though I believe, in this case, the whole mass consists of flakes of that mineral without any alternation

* The term "foliated," however, as applied to schistose rocks, such as *mica schist*, and distinguished from "cleaved" as applied to *slate*, was first suggested by Professor Sedgwick in his paper on the "Structure of large mineral masses."—(*Geological Transactions*, vol. iii., pp. 479 and 480.)

of quartzose layers. The same remark holds good with respect to the rarer rock called *actinolite schist*. As far, indeed, as my own observation goes, I should doubt the existence of these rocks in any other form than as the result of a partial metamorphosis of some hornblendic "ash," or of some other mechanically formed rock, derived from the wear and tear of a greenstone or a syenite.

67. *Gneiss* is probably of all others the most completely metamorphosed rock that retains any mark of its original mechanical structure.

Some gneiss can only be distinguished from granite by the regular arrangement of its component crystalline particles in a certain parallelism, so as to give it a slightly schistose structure, or "grain," as it is called by Professor Sedgwick. Other varieties of gneiss, again, can only be separated from mica schist by the occasional occurrence of little plates of feldspar in addition to the layers of mica and quartz. In hand specimens, indeed, it is often very difficult to draw any sharp line of separation between mica schist and gneiss, the more fissile specimens being called mica schist, while the firmer ones would be called gneiss. Even in the field they are often so blended together, and alternate with each other so frequently, that their separation is impossible. There is therefore almost every gradation from dull clay slate through glossy and so called talcose slate into mica schist and gneiss, and thence into actual granite.

Gneiss might, indeed, in its purest and most typical form, be termed schistose granite, consisting, like granite, of feldspar, mica, and quartz, but having those minerals arranged in layers or plates, rather than in a confused aggregation of crystals. In speaking of it as schistose granite, however, we must never forget that true gneiss was never really a granite, with a peculiar laminated structure, but that it was originally a laminated mechanically formed rock, a *sandstone* more or less argillaceous, containing, indeed, the elements of quartz, feldspar, and mica, but not exhibiting any more appearance of those minerals at its first deposition than is exhibited by any of the ordinary unaltered sandstones with which we are familiar.

It would be difficult, without going into a tediously minute detail, to attempt to give a more precise lithological description of gneiss, since some specimens are precisely like a crystalline kind of sandstone ; others may be called "gneiss" or "mica schist" indifferently, while others could not be described in terms that would not equally apply to granite.

There are parts of the granite of the south-east of Ireland where it passes into a rock that might be called gneiss from the parallel arrangement of its mica flakes, but this is merely in a few isolated spots for a distance of a few feet, just as in other spots the mica becomes plumose with the plates arranged into half radiating bunches, like Prince of Wales' feathers.

Some of the metamorphic rocks of the Alps, on the other hand, which are, I believe, in reality gneiss, nevertheless resemble granite so completely, that no one looking at a hand specimen, or even a single block, however large, would venture to pronounce it other than a genuine granitic rock, formed of a confusedly crystalline aggregate of feldspar, quartz, and a dark green mineral which is either a dull earthy mica, or takes the place of mica. I believe some of this granitic-looking rock, if not all of it, to be the so-called Protogine. If it were true granite it would, as Professor Haughton has remarked, be difficult to believe the third mineral to be talc, *i.e.*, a pure silicate of magnesia. But, whatever be the exact nature of the third mineral, I do not believe the rock to be a granite, but merely a granitoid gneiss.* Lithologically, it is doubtless not to be distinguished from granite, but its petrological relations prove it to be gneiss, in consequence of its bedded character and its regular inter-stratification with every variety of mica schist and gneiss, and that often in beds not more than a few feet in thickness. There seemed to be a regular alternation between the most granitic and the most earthy schistose bed, the extreme varieties sometimes lying in direct apposition against each other, sometimes separated by intermediate gradations. The granitic beds, too, were certainly not intruded veins, but ran evenly between the other rocks, and were evidently contemporaneous with them.

In the pass of the Tête Noire, between Martigny and Chamounix, the traveller may see, just opposite the door of the Tête Noire Hotel, even a conglomerate converted into a metamorphic rock. This is a confused aggregate of mica flakes, enclosing and surrounding pebbles of white quartz, which vary in size from that of a nut to that of a man's head. The mica was not deposited in worn spangles as a mere micaceous sandstone or clay enclosing quartz pebbles; or if it was so formed, those worn micaceous spangles have been made to blend together again, and form a rough mica schist, enveloping the pebbles in continuous flakes like any other mica schist.

It seemed to me from my rapid glance at the Alps, that a great set of beds which were originally formed as ordinary mechanically deposited rocks, argillaceous and arenaceous, alternating with each other in great variety, and containing, some more refractory, some more easily reducible substances, had been all acted on together, while deep in the earth, by the metamorphic agency of heat (together with water and whatever other solvents might be necessary to set the chemical agents at work), and that the whole had been accordingly changed together and brought into their present crystalline, semi-crystalline, or schistose state, and eventually tilted up into a vertical position, thrust

* I am alluding now to the rock as seen in the Hasli valley about the Handek waterfall, and about the Grimsel Hospice.

up towards the surface, and exposed at it by the removal of the superincumbent mass.

I shall have occasion to allude to this subject again, when speaking of the surface forms of different kinds of rock.

While stating my belief that all gneiss was once sandstone, I by no means intend to assert that all sandstones could be converted into gneiss, for it is obvious that purely siliceous sandstones could not, but *purely siliceous* sandstones are much more rare than is often supposed. The great mass of sandstones and of clays do contain the elements of feldspar and mica as well as quartz—that is to say, they contain alumina, iron, potash, soda, magnesia, etc., as well as silica.

Passage of Metamorphic into Igneous Rocks.—We must also never forget that the extreme term of metamorphism by heat is actual fusion and reduction into the state of an igneous rock, and that it is possible therefore that some igneous rocks, nay, even some true granites, may be metamorphosed rocks, aqueous rocks that have been completely melted down and absorbed into the igneous interior of the globe.*

If we look upon *all* aqueous rocks as in some shape or other *derivative* rocks—and this is a conclusion from which we cannot escape—we must regard them as either mediately or immediately derived from igneous rocks. With regard to the mechanically formed aqueous rocks this is obviously true, because if we trace to their original source the silica and alumina, the quartz, the feldspar, and the mica of which they are made up, we must eventually arrive at some igneous, most probably some granitic, rock as their parent.

But even as regards the lime and the soda, and magnesia of all the chemically and organically formed aqueous rocks (setting aside the carbonaceous rocks), we are compelled to suppose that the water first derived those minerals from the decomposition of such igneous rocks as contained them. The carbonates of lime and magnesia, and the sulphates of lime, must have acquired their bases primarily from the decomposition of the silicates of lime and magnesia, which are to be found in the igneous rocks; carbon being the only element which does not seem primarily derivable from them. Speaking generally, then, it need not surprise us to find materials that had once been fused reduced again to that condition. It is true, that the matters that acted as a flux to the silica and alumina of the igneous rocks may have been washed out and removed more or less completely from the debris of those rocks which form our sandstones and clays; but purely siliceous sandstones or pure clays are comparatively rare and in small quantity, and if the rocks around them and enclosing them were remelted, they

* From some recent observations, especially those of Professor Haughton and Mr. Scott on the rocks of Donegal, it would appear that much more granite has this metamorphic origin than has hitherto been supposed.

would soon become mingled with the other rocks which retain their basic constituents, or consist more or less entirely of basic materials, and thus might again enter into the constituents of the igneous rocks.

There can, therefore, be nothing either unphilosophical or improbable in regarding, with Sir C. Lyell, the whole crust of our globe as consisting of materials passing through an endless cycle of mutations, existing at one time as igneous rocks, then gradually decomposed, broken up, separated out, sorted, and deposited as aqueous rocks, whether chemical, mechanical, or organic, at a subsequent period metamorphosed, and ultimately re-absorbed into the igneous rocks.

In this view, the most highly metamorphosed rocks would be those most nearly hovering upon the brink of re-absorption,* and gneiss accordingly on the point of passing into granite, and in some cases almost undistinguishable from it.

Metamorphism of Igneous Rocks.—Neither is metamorphism confined to the aqueous rocks, but is probably equally active among the igneous rocks themselves, although there, the processes are more concealed from us. Many rocks which are now undistinguishable from true igneous rocks, may have been formed by a comparatively slight metamorphism of "ashes," or other mechanical accumulations of materials derived directly from igneous rock, and subsequently brought within the influence of heat. It is probable that many amygdaloids may be altered tuffs, and possible perhaps that some clinkstones, whether volcanic or trappean, may have a like origin. Some felstones, again, may be but baked and slightly altered feldspathic ash.

Some real and originally formed igneous rocks may in like manner undergo metamorphoses, more or less complex. Some felstone or greenstone porphyries, for instance, may have acquired their porphyritic structure by long-continued and comparatively gentle heat, acting on previously compact trap rocks. The same comparatively slight action of heat may have caused many once compact or porphyritic igneous rocks to have become completely crystalline, and possibly may in some cases have generated new combinations, and produced mineral forms that did not exist in the original rock. Trappean rocks may thus have become granitic. These possibilities should be borne in mind when we are endeavouring to explain phenomena that otherwise are often difficult to understand.

Tabular Classification of Rocks.—It will perhaps be useful if we give here the foregoing classification of rocks in a tabular form.

* Such speculations as those in the text may be useless enough as far as any practical result to be derived from them, and may by many persons be thought uncalled for. The old ideas, however, of the original independent origin of mica schist and gneiss still linger in some men's minds, and are even, as I am informed, coming more and more into favour with some continental geologists.

IGNEOUS ROCKS.

VOLCANIC.

Essentially Feldspathic.		*Feldspar and Augite*
Trachyte	Trachydolerites, or intermediate varieties unnamed.	Dolerite.
Trachytic Porphyry.		Anamesite.
Pearlstone.		Basalt.
Domite.		Nepheline Dolerite.
Andesite.		Leucite Rock.
Clinkstone.		Amygdaloid.
Obsidian.		
Pumice.		
Tuff.		Peperino.

TRAPPEAN.

Siliceo-feldspathic.		*Feldspar and Hornblende, etc.*
Felstone.	Intermediate varieties unnamed.	Greenstone or Diorite.
Pitchstone.		Euphotide or Gabbro.
Clinkstone.		Hyperite.
Feldspar Porphyry.		Melaphyre.
		Diabase.
		Aphanite.
		Lherzolite.
		Variolite.
		Kersantite.
		Eclogite.
		Disthene Rock.
Feldspathic Ash.		Greenstone Ash.
		Wacké or Claystone.

GRANITIC OR SUPER-SILICATED ROCKS.

Quartzo-feldspathic.	*Quartzo-feldspathic with Hornblende, or Mica, etc.*
Pegmatite.	Syenite.
Elvanite.	Granite.
Eurite.	

AQUEOUS ROCKS.

Mechanically Formed.

Arenaceous	Gravel or Rubble. Conglomerate or Puddingstone, and Breccia. Sand. Sandstone and Gritstone, and their varieties.
Argillaceous	Clay and Mud. Clunch. Loam. Marl. Shale or Slaty Clay.

Chemically Formed.

Calcareous	Stalactite and Stalagmite, Travertine, etc. Some Dolomites ?
Siliceous	Siliceous Sinter.
Gypseous	Gypsum.
Saline	Rock Salt.

Organically Derived.

Calcareous, mostly from animals	Limestone and its varieties, compact, crystalline, chalky, oolitic, pisolitic, some magnesian, etc.
Siliceous, probably from animals	Flint and Chert.
Carbonaceous, mostly from plants	Peat. Lignite. Coal. Anthracite. Graphite.

AERIAL OR EOLIAN ROCKS.

Blown Sand on coasts.
Sand-hills of deserts.
Calcareous Sands compacted by rain, etc.
Debris at foot of cliffs.
Volcanic Ashes, etc., falling on land.
Soil.

METAMORPHIC ROCKS.

Those in which the Original Structure is still Apparent.

Arenaceous . .	Quartzite or Quartz-rock.
Argillaceous . .	Hornstone, Clay Slate.
Calcareous . .	Primary, Crystalline, or Saccharine Limestone, or Statuary Marble. Some Dolomites. Serpentinous Limestone, Verde Antique, etc.

Those in which the Original Structure is more or less completely Obscured or Obliterated.

Schistose Rocks . .	Mica Schist. Chlorite do. ? Talc do. ? Hornblende do., etc. ? Gneiss.

PART I.

GEOGNOSY.

SECTION II.—PETROLOGY.

CHAPTER IX.

FORMATION OF ROCK-BEDS.

THE term Petrology is here used rather arbitrarily to signify the study of rock masses; that is to say, the examination of those characters, structures, and accidents of rocks which can only be studied on the large scale, and only be observed in "the field." It will include the modes of stratification, of separation by divisional planes, of fracture and disturbance, of denudation and its results, the methods of occurrence and form of igneous rocks, and their relation to aqueous rocks, the origin and growth of mountain chains, and the formation of mineral veins.

Lamination and Stratification.—The lamination and stratification of the aqueous rocks is the very foundation of geology, that on which all the more important deductions of the science are based. It is therefore necessary to describe these structures in some detail.

The stratification of rocks is their division into separate strata or beds.

The lamination of a rock is the separation of its stratum or bed into its component laminæ or layers.

Strata vary in thickness from a few inches to several feet.

Laminæ rarely exceed an inch in thickness, and vary from that down to the thickness of the finest paper.

The very fine laminæ (plates or layers) of which some beds of shale are made up, have been already mentioned. Each of these little layers of earthy matter is obviously the result of a separate act of deposition;

the whole bed of shale being formed by the gradual settlement of fine sediment, film after film, upon the bottom of some tranquil or very slowly moving water. We may suppose this sediment to have been carried into the water by successive tides bringing matter from some neighbouring shore, by frequent or periodical floods of some river, by the gradual action of some current, or by any other agent which could transport fresh materials, at different intervals, into the water. Whatever may have been the exact nature of the action, it was clearly a gradual, and not a sudden one; and some considerable time must, under any circumstances, be allowed for the deposition of a bed even *one* foot thick, when we find it, as we often do, made up of distinct laminæ, fifty or a hundred of which may be counted in each inch of its thickness. This time is that required for the mere act of settlement in the water, without calculating that which is requisite for its transport from some distant locality.

Still, although some time was required, and although the acts of deposition were distinct, yet they were not so widely separated in time as to allow of any great consolidation of one layer before the next was deposited upon it. The whole set of laminæ succeeded each other so as to cohere together, and form *one* bed, which may be quarried and lifted in *single* blocks.

In some shales, certainly, the coherence between the laminæ is but slight; they may be pulled asunder by the hand; but in others it is more complete, and in some quite firm; and in some fine-grained laminated grits and sandstones, it requires almost as much force to split them along the lines of lamination (*with the grain*, to use a common term) as it does to break them across. In such instances, it is probable that the succession in the acts of deposition was a more rapid one, than when the laminæ separate more easily. The mere degree of coherence, however, of the laminæ of a stratum is by no means so sure a test of the shortness of the intervals between their deposition as their distinctness is of its length, since all the subsequent actions of pressure and cementation tend to force them to cohere, while there is no action which can possibly tend to separate them, unless that of weathering close to the surface.

The planes of stratification differ from those of lamination, in as much as they mark a total want of coalescence between two contiguous layers of rock.

It would be impossible to get a block consisting of parts of two beds, since the parts would fall asunder and make two blocks.

It is true that in some cases parts of two beds may partially adhere together if carefully removed, but this is obviously the adhesion of two things, and not their coalescence into one. It is also true, that in some rocks the lamination, and in some even the stratification is more or less

obscure. In such cases, the indistinctness may be done sometimes to the comparative rapidity and continuousness of the act of deposition, but in others it is due to the subsequent obliteration of structures once possessed.

Such cases are quite the exception to the rule, and do not at all invalidate it.

If the coherence of the laminæ of a bed is the result of the comparative shortness of the intervals between their deposition, it follows that the want of coherence between one bed and another is the result of the length of the interval between the deposition of the beds. Each bed had time to become consolidated, to a greater or less extent, before the next was deposited upon it, so that the latter could not at all coalesce with the former. The planes of stratification, then, mark an interruption in the act of deposition, a pause during which nothing was deposited; the duration of that pause being very considerably longer than that of the intervals between the successive laminæ.

In using the term "plane," we, of course, must not take it in its strict mathematical sense, since the surfaces both of laminæ and beds are often uneven. In speaking of the planes of lamination, moreover, we must often understand merely the direction in which the laminæ are arranged, whether they be separable from each other or not.

When we examine a cliff or a face of rock which cuts across the planes of lamination or stratification, we speak of them as lines.

If we are at a loss to estimate the length of the interval between the deposition of the successive laminæ of a bed, still less have we the means of calculating the time which elapsed between the formation of one bed and that which rests directly upon it. When two or more successive beds are of precisely similar character, as two beds of the same kind of shale or sandstone, we should naturally suppose that the interval between bed and bed was not indefinitely greater than that between lamina and lamina. If we assigned days to the one, we might allow weeks to the other, if we gave months to the one, years might be given to the other, and so on. Still we should have no certain grounds to go on, and the interval between bed and bed might be centuries or thousands of years for anything we could, in the majority of instances, shew to the contrary. When, moreover, the two beds were of totally different characters, as, for instance, where a bed of sandstone or limestone rested on a bed of shale, or *vice versa*, we should feel called upon to allow a larger interval between their deposition than where the beds were similar. Some time must be required for a change to take place in the conditions of the neighbourhood. In the case of a bed of sandstone destitute of all argillaceous matter resting on a bed of shale, we should be obliged to suppose some alteration in the strength or direction of the currents, so that all the finer matter was swept away, and only

the coarser or heavier deposited. In the case of a shale resting on a sandstone we should suppose that the current had diminished in velocity compared with that formerly acting. In either case the current might have come from a new quarter where only the particular kind of material was to be got.

The same current of water charged with a mixture of gravel, sand, and mud, and having strength enough to carry it all on together, will, as its strength lessens, sort and separate the materials from each other, depositing them in the order of their coarseness, the pebbles and coarse sand first, next the finer sand, and lastly, the mud.* Three different kinds of rock, then, might under certain circumstances be deposited at the same time by the same current in different places. But in order that either sand or gravel may be thrown down at a subsequent period on the top of the mud, a fresh current either of greater velocity or from a nearer source will be required, while an interval will be necessary for the mud to consolidate so far as not to be removed by the new current, and not to allow the fresh pebbles or sand to sink into it.

In the case of a limestone occurring either on shale or sandstone we are still more forcibly led to the supposition of a great change of conditions. If the limestone be a pure carbonate of lime without much or any admixture of mechanical detritus, it is obvious either that all currents had ceased in the water which had previously deposited the sandstone or the shale, or else that they were no longer able to get any earthy matter and transport it to that place. If, indeed, as seems necessary in the case of all marine limestones, we assign an organic origin to this rock, we are compelled to allow a period prior to its production sufficient for the animals from which it was derived to grow and to secrete their solid materials from the adjacent water.

It is possible, indeed, in some cases, by the aid of the remains of animals and plants found fossil in the rocks, to arrive at something like a rough approximation to the time which has elapsed between the formation of successive beds, so far as to say whether it was long or short. There are cases, for instance, in which we find on the surface of a bed of limestone the roots or attachments of a particular class of marine animals, called encrinites, which when alive were fixed to the rock by a solid calcareous base. These attachments belong to animals of all ages, and are in great numbers; and in a bed of clay which rests immediately on the limestone, there are found a multitude of the remains of the upper portions of these animals, likewise of all sizes and ages, see fig. 10. Now it is plain that in this case, after the limestone was formed, there was an interval during which the sea was quite clear and free from sediment, and therefore well adapted for the growth of these

* Just as was previously shewn for mud of different degrees of coarseness in Mr. Babbage's observations, see p. 110.

animals. We do not know how long it remained so before any of them began to live there, but after a time they settled on the limestone at

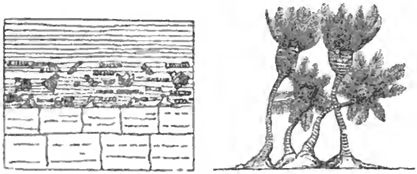


Fig. 10.*

Beds of oolitic limestone covered by brown clay containing fragments of encrinites. Living encrinites attached to sea bottom.

the bottom of the sea, and grew and flourished there for a sufficient period to allow of successive generations arriving at maturity undisturbed, before the time when a quantity of mud, having been carried into the water, was deposited upon them, and killed them, and at the same time buried their remains. Some of these remains, even the insides of the joints, are coated over with the calcareous cases of serpulæ (a kind of sea-worm), shewing that they had been unburied in the bottom of the sea for some years, while their descendants were growing about them. Here, then, we have an interval of many years, if not of centuries, between the formation of two beds which rest directly one upon the other.—(*Lyell's Manual*, ch. xx.)

Many instances similar to this occur to the geologist when pursuing his investigations, although not often admitting of such clear illustration and description.

On the other hand, we have instances of fossil trees passing through several beds of sandstone, in such a way as to shew that the whole number of beds were accumulated after the tree had sunk, and before it had time to rot entirely away. These trees evidently became water-logged, and sunk to the bottom, where they rested in an inclined position, anchored by their roots, while successive deposits of sand were accumulated around them. But a tree thus wholly buried in water will last many years before it is entirely decomposed, so that it might very well have become enclosed in several beds of sandstone, especially when we recollect that it forms an obstacle to the currents flowing by it, and thus tends to check their force, and cause the deposition of sand around it more rapidly than would otherwise take place. In Emmous's American geology, a case is mentioned of the stumps of pines still standing erect on the bottom of the sounds or shallow inland seas along the

* Copied from Lyell's Manual.

coast of North Carolina, although the period of the submergence of the land on which they grew is quite unknown. Still, whatever number of years we assign to the accumulation of the whole mass of sandstone, we should be inclined in this case to suppose the deposition of the sand to have been comparatively rapid, and the intervals between the deposition of the beds comparatively short.

It is possible in some cases, even without the aid of organic remains, to discover that the interval between two adjacent beds was a long one. For instance, we not unfrequently find that two beds, which in one place are contiguous, do in another place let in one, two, or more separate beds between them, as in Fig. 11, which is taken from a sketch made in a quarry at Donnybrook, near Dublin, by Mr. Du Noyer. It is obvious, that if we observed the beds *a*, *e*, at the spot marked A, we should only suppose an ordinary interval to have elapsed between the times of their deposition ; while on tracing the beds to B, we are compelled to enlarge that space of time sufficiently to allow for the formation of the beds *b*, *c*, and *d*, and the *intervals between them*. It appears, then, that while we are able to assign a sort of rough limit to the time required for the deposition of one bed, composed of a number of laminæ, we are rarely able to assign any approximate limit to the time required for the formation of a number of beds. Not only have we to multiply the first period by the number of the beds, but to allow for an equal number of intercalated intervals, of altogether uncertain duration, to represent the pauses that occurred between the formation of each two contiguous beds.

Fig. 11.

These intercalated intervals would be most probably *greater* than the periods of deposition, because we cannot imagine any circumstances that can keep up a continuous or rapid deposition of earthy matter, whether chemical or mechanical, for a long period of time, in any one particular locality. All we know, or can conceive, of the accumulation of earthy matters in the seas or lakes of the present day, shews the action to be partial and occasional, a bed of sand being formed here, a patch of mud deposited there, a bank of pebbles accumulated in one place, a bed of oysters or other shells growing in another, so that the bottom of the sea becomes gradually covered by several unconnected patches of deposition of different kinds, lying side by side. All our experience shews that for any great thickness or vertical succession of beds like these to be formed, in other words, for the depth of water to

be materially diminished (except in narrow bays and inlets), a great length of time is required.

The soundings in shallow and well-frequented seas, such as those around the British Islands, certainly do not alter very rapidly, although they doubtless do change in the course of years or centuries. In the charts originally used in navigation, the character of the bottom is marked in different places as "mud," "sand," "sand and shells," "small stones," and so on, and these characters remain sufficiently constant from year to year, to be used in combination with the depth of water as a guide to the seaman, and enable him to determine the situation of his vessel. These charts remain trustworthy guides certainly for many years. This shews us that the deposition of these materials is not going on so rapidly in our own seas, as to materially alter either the depth or the nature of the bottom, in any short space of time; perhaps not for many centuries.

In a vertical series of beds of rock, then, we may feel sure that each bed will be to that below it like Salius to Nisus in the foot race, "proximus huic, longo sed proximus intervallo;" and a third will follow "spatio post deinde relicto." Whether we take the whole earth generally, or any particular sea or ocean, and limit ourselves to the consideration of any given period of time, we must look upon the deposition of mineral matter as the exception, not the rule. Of many hundred thousand square miles of sea, only one perhaps is receiving at any one time, the accession of any mineral matter on to its bed. The next successive deposition may be very long deferred, and may occur either in an adjacent or in a widely separated locality; and a vast number of these partial and detached acts of formation will be required before the whole of any particular area can be covered with one or more beds of rock. In reasoning on the methods of production that have been concerned in the formation of our great series of stratified rocks, which are nothing else than so many old "sea-bottoms," we are compelled to suppose a gradual, partial, and interrupted action to have operated in their accumulation, like that which is producing similar beds in the seas and lakes of our own time.

When we rise from the consideration of a series of single beds to that of a succession of groups of beds, we find instances, on a still larger scale, of intervals having taken place in the deposition of strata, which at first sight appear perfectly continuous. Mr. Prestwich, in his paper on the "Correlation of the Eocene Tertiaries of England, France, and Belgium" (*Journal of the Geological Society of London*, vol. xi., p. 211), shews that on examining the rocks called Tertiary, which lie above the chalk in France, they appear to have a regular continuous sequence of beds of sand, and clay, and limestone, in which there is no sign of any interval having happened, while in reality a group of the English tertiaries, known as the London clay, having a thickness of nearly 500

feet near London, was deposited in an interval between the formation of two of the French beds.

Mr. Prestwich says, speaking of the series as it exists in France, "Lithological structure and superposition seem to indicate a complete and perfect series. . . . It would nevertheless seem that there is a very important interval between the 'Lignites of the Soissonnais' and the 'Lits Coquilliers,' and that at so short a distance as from Kent to the Department of the Oise, there is introduced, wedge-shaped, between these two deposits, the large mass of the London clay, with its multitude of original organic remains. Yet there is not only no evidence either of the great lapse of time, or of the important physical changes which such a formation indicates, but there is even no cause for suspicion of such a fact in the apparently complete and continuous series of the 'Sables Inferieurs' of the north of France." We cannot conceive the London clay to have required less than some thousands of years for its formation, and it may more probably have been many tens of thousands, during which interval no corresponding deposition was taking place over the area now forming part of the north of France, though deposition did take place both before and after this period, equally in the seas which covered what is now France, and what is now England.

Still larger groups of beds even than that have occasionally to be intercalated into a series. The "Carboniferous slate formation," for instance, of the south-west of Ireland, swells out to a maximum thickness of not less than 5000 feet in one direction, while in another, not more than 20 miles distant, it dwindles down to 50 or 100 feet, and maintains that diminished thickness pretty constantly over a very large area, not the least trace being discernible within that area of the absence of so vast a series of beds, as may be seen in the adjacent one.

These facts have not hitherto been sufficiently insisted upon, since they have a most important bearing on the theoretical conclusions of geologists.

If we look upon the laminæ of a stratum, as so many leaves of a book, or as so many marks on a tally, proving that they were formed in succession one after another, and then consider the strata placed one above another as so many volumes, or so many tallies, used and stored up in succession, we are quite justified in taking them as positive evidence for the lapse of time. Each act of formation required a certain time for its performance, and the total number of the acts prove the lapse of a certain total period of time.

It is very natural to look to this positive evidence only, and to forget that we have no means of verifying the paging of the leaves or the numbering of the volumes, or of determining what were the intervals between the marks on the tallies, whether they were made regularly

and consecutively, on any one tally, or whether in any particular place we have the perfect series of tallies.

Such considerations as these just now laid before the reader, will make him cautious in taking for granted a continuity in the series, which can never be proved. It is quite impossible in any quarry to say of one bed that rests directly on another, that it was not only the next formed bed at that particular place, but that no other bed, or even no other set of beds, was formed anywhere else in the interval between them. If he place his finger on the plane of stratification between two beds, that little space may mark the lapse of years, centuries, or millenniums.

Extent and termination of Beds.—The fact of the presence of a set of beds in one locality, and their absence in another, whether that set be one of the large groups which we call "formations," or merely two or three beds ending in a quarry, as in fig. 11, leads us to another conclusion respecting beds of stratified rock, namely, that although sometimes very widely spread, they are not of indefinite extent, but must end somewhere. This ending is generally a gradual one, the bed becoming thinner and thinner, till at last it disappears. Sometimes, however, though rarely, the termination is more abrupt.

Whether we reason from experience, or from the nature of the case, we should never be led to believe that the deposition of sediment in water, whether it be a chemical or a mechanical one, could, except in very rare instances, be co-extensive with the whole water. With respect to the sea, we cannot conceive any natural causes which could produce such an universal and simultaneous deposition. The wonder perhaps is, that single beds sometimes extend over such very wide areas as we really find them to occupy.

The extent of single beds is most certainly ascertained in coal mining, in which the horizontal (or lateral) extension of beds is followed. Particular beds of coal, or of shale, or other rock, having recognizable characters, are sometimes known to spread throughout a whole district. For instance, in South Staffordshire a bed of smooth black shale, a little below the Thick or Ten-yard coal, is known as the "Table batt." It has a thickness from two to four feet, and extends over all the greater portion of the South Staffordshire coal field—places where it is known being ten or twelve miles apart from each other in different directions. Its original extension was probably much greater since the beds now disappear in one direction by "cropping out," and are buried in others at too great a depth to be followed. Known beds of coal, with a particular designation, such as "Heathen coal," extend over still wider areas, and similar facts occur abundantly in most coal fields.*

* Mr. Hull in his little work lately published on the "Coal Fields of Great Britain," says, "that one bed of coal called in part of the Lanarkshire coal-field the 'Arley mine,' but

Neither is the great extension of single beds confined to those containing coal, but is found wherever there are beds of a sufficiently remarkable character to be noticed and recognized. A little bed called the Bone bed, from its containing peculiar fragments of fossil bones, which lies just at the top of the New Red sandstone of the south of England, is found both at Axmouth in Devonshire, and at Westbury and Aust in Gloucestershire—places fully sixty miles apart—the bed itself never being more than two or three feet thick, and frequently only as many inches. It is even stated by Mr. Strickland, that he has identified this same bed in the form of a white micaceous sandstone up to Defford in Worcestershire, 104 miles from Axmouth, and at Golden Cliff and St. Hilary in Glamorganshire.—(*Proceedings of the Geological Society of London*, vol. iii., pp. 585 and 732). Similarly, a Bone bed at the junction of the Ludlow rock and Old Red sandstone, never more than a foot thick, and frequently only one or two inches, has been traced at intervals over a space of forty-five miles from Pyrton Passage to the banks of the Teme near Ludlow.

I have myself observed in the south of Ireland a little bed of peculiar quartzose conglomerate about a foot thick in the middle of the Lower limestone shale at Ardmore and in Ballycotton bay, places full 16 miles apart, and even found a precisely similar bed in the same black shales at Kilworth near Fermoy, which is 25 miles to the north-west of Ardmore. The triangular area defined by those three places would be one of 200 square miles.

Whether these beds be absolutely continuous or not over all the intervening spaces, these facts are sufficient to prove the uniformity of conditions over very large areas, so that wherever deposition took place, it was of precisely the same character. In the case of the bone beds mentioned above, the conditions under which they were deposited seem to have been so very peculiar that they may perhaps be looked upon as exceptions rather than as examples of a rule. It is useful, however, sometimes to know what is possible as well as what commonly occurs; neither, probably, would they be found to be very uncommon, if it were more often possible to trace a single bed over the whole area which it occupies.

When from a single thin bed we come to the examination of a group of a few beds, the instances of mineral identity over very wide areas become still more frequent. This is especially observable when the group of beds is of a character quite different from the larger mass of rocks in which they lie; provided that difference points to a state of greater tranquillity or quietness of action during the time of deposition, as would a bed of clay occurring in a group of sandstone beds, or

known by other names in other parts, spreads over the greater part of the coal-field which has an area of 192 square miles."

a bed of limestone or coal occurring in others having a purely mechanical origin.

We may take, as an example, what is called the Bala limestone in North Wales. This is a little group of a few beds, rarely exceeding twenty feet in thickness, lying in a series of gray slaty rocks several thousand feet in thickness. The lowest bed is generally a black crystalline limestone, over which are several beds of hard crystalline concretionary and nodular limestone of a gray colour, alternating with more shaly or slaty beds. These contain small black nodules possibly of a coprolitic origin.* The softer argillaceous bands wear away more rapidly than the crystalline layers, which accordingly stand out in relief like a cornice moulding. By these characters the Bala limestone may often be perceived at the distance of half a mile on the side of a hill, and distinguished from the rocks of hard gritty slate above and below it. It extends from near Dinas Mowddwy on the south, to Cader Dinmael, on the north, a distance of 22 miles, and from near Llanrhaidr yn Mochnant, on the east, to the valley of Penmachno on the west, a distance of 24 miles; thus occupying an area of 400 or 500 square miles at least. It probably was once much more extensive; because, though we reach its apparent original termination in one direction near Dinas Mowddwy, where it dwindles to a thickness of two or three feet, in others its present "outcrop" shews no symptom of diminution of thickness or other sign of original termination.

The little group of black shales just now spoken of as the Lower limestone shales, is always found just at the base of the Carboniferous limestone in the south of Ireland, from Kerry and North Cork, to Waterford and Wexford, over an area of 150 miles in diameter, and occurs again with precisely similar characters beneath the Carboniferous limestone that surrounds the coal-field of South Wales. It varies in thickness from 20 to 200 feet, having very constant lithological characters over all that space, besides extending over an area in South Cork, where it forms the upper part of a far larger mass of similar beds.

On the other hand, some beds, even of a considerable thickness, have a remarkably small extension, being mere cakes, thick in the middle, and thinning out rapidly in every direction. This happens sometimes with all kinds of aqueous rocks; but is the more usual characteristic of the coarser mechanically formed rocks, being more common in sandstones than in clays and shales, and more frequent in conglomerates than in sandstones.

Beds of sandstone in the coal districts are sometimes found to thicken or thin out very rapidly. This is easily observable where sandstone beds are known to the colliers by specific names, and where the coal pits are near together. The miners are occasionally thrown

* A "coprolite" is the petrified dropping of some animal.

out in their calculations as to the depth at which particular coals will be found by these irregularities, which are sometimes so great and rapid, as to be called "faults" by men not accustomed to precision in the terms they use. Such an instance occurs near Wednesbury in South Staffordshire, where a bed of sandstone known by the name of the "New Mine rock" thickens out from nine feet to seventy-eight feet in the course of a few yards' horizontal distance. In other parts of the district this sandstone varies from fifteen to sixty feet, and in some places is entirely wanting.

In examining sandstones and conglomerates, the conglomerates or old gravel beds are often found to be very partial and irregular, forming steep-sided banks and mounds enveloped in sand.

In these cases, although it was obviously a work of time for the pebbles to have been ground down from their original large and angular condition to their present small rounded form, and although we may very well suppose them to have been washed about from place to place, and thus to have eventually travelled far from their original site, yet their final deposition in the place where we now find them was probably a rather rapid action.

Conglomerates, then, may be quoted as examples either of the *length* of time required for their formation or of its *shortness*, according as we look to the *preparation* of their materials or the actual *deposition* of them. This remark holds good, too, with respect to all other coarse mechanically formed rocks.

Relation between the Extent and the Composition of a Bed.—It may be stated as a general rule, that the finer the materials of which a bed is composed, the wider is its area and the more equable its thickness, and the rule holds equally good for groups of beds.

In a group of beds made up of alternations of fine-grained and coarse materials, the variations in thickness in different parts of its area, are generally due to the changes that take place in the coarser beds.

In other words, the extent and equability of beds is generally in direct relation with the specific gravity of their materials, or at least with their capacity for floating, those which sank most slowly being most widely and equably diffused through the water, and *vice versâ*.

A most remarkable example of the above rule is afforded us in the South Staffordshire coal field, where a group of "Coal-measures" composed of alternations of clays, sandstones, and coals, which at Essington is between 300 and 400 feet in thickness, thins out towards the south, by the gradual dying away of the shales and sandstones, so that in the space of five or six miles the different beds of coal come to rest directly one upon the other, and are continued for ten miles at least towards the south as a compound seam of coal, thirty feet thick, with but a few shaly partings between the beds.—(*Mems. Geol. Survey*, S. Staff. coal-field, 2d Ed.)

The principal varieties of stratified rock are usually found in beds which are thinner, more extensive, and more equable, in the following order :—1. Conglomerates, the thickest, most irregular, and occupying the smallest area; 2. Sandstone; 3. Clay or shale; 4. Limestone; 5. Coal, the thinnest, most regular, and most widely spread.

Irregular and Oblique Lamination and Stratification.—In shales the laminæ are remarkably thin and regular, all parallel to each other, and parallel also to the planes of stratification. In many fine-grained, and in some coarse-grained sandstones, this regularity and parallelism likewise prevails. In other sandstones, however, great irregularity is observable in the laminæ of which the beds are made up, the layers of different coloured or different sized grains being oblique to the planes of stratification, and various sets of layers lying sometimes at various

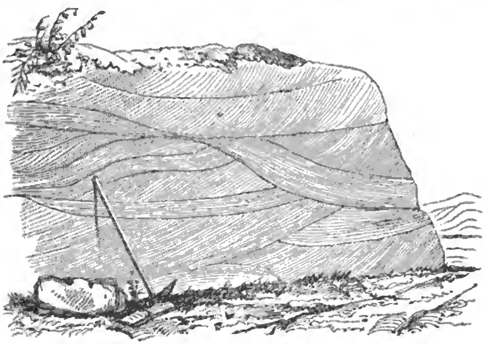


Fig. 12.

angles and inclining in different directions in the same bed, as in fig. 12, which is taken from a sketch made on the coast of Waterford.

This structure is a proof of frequent change of direction, and probably of strength, in the currents which brought the sand into the water. If we suppose a current of water running over a surface which ends in a slope, as at *a*, in fig. 13,

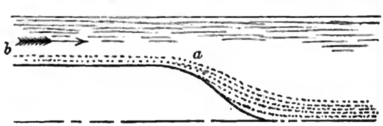


Fig. 13.

it is clear that any sand which is being drifted along the bottom from *b*, will, on reaching *a*, roll down into the comparatively still

water of the deeper part, and remain there probably undisturbed. Layer after layer of sand may thus be deposited in an inclined position according to the slope of the bank.* On the other hand, if any obstacle arrests the sand which is being drifted along the bottom of any water, some of it will be piled up into a heap, and a bank will be then formed having laminæ more or less inclined. If the current shifts its direction, another bank may be formed with its laminæ inclined at a different angle or in a different direction. Moreover, after one bank has been formed, a subsequent change in the velocity or the direction of the moving water may cut off and remove a portion of it, or excavate a channel through it, and this hollow or fresh surface may be again filled up or covered over by layers having a different form from the first. In this way water subject to changes of current, especially shallow water full of eddies, will throw down or heap up materials in a very confused and irregular manner.

Oblique lamination of beds is carried out sometimes to such an extent as to produce several beds, sometimes of no slight thickness, which lie obliquely to those above and below them. Instances of this were observed and described by Mr. G. V. Du Noyer in the Dingle promontory, on the west coast of Ireland. He pointed out to me such series of beds lying obliquely to each other, both in the cliffs and in the shores exposed at low water.

I have also observed a similar case in South Staffordshire, where, over a space at least a quarter of a mile across, quarries were opened shewing beds of sandstone inclined at an angle of 30°, while a horizontal bed of coal stretched a little way below over the whole area.

It is a modification of the same action probably which has produced what are called "rolls," "swells," or "horses' backs," in the Coal Measures, and probably in other rocks where they remain less noticed.

A long ridge, and sometimes one or two parallel ridges, of clay or shale are occasionally found rising from the floor through one or more beds of coal, "cutting them out" for a certain distance, to use the miners' terms. The crest of such a ridge is sometimes eight feet above the floor of the coal, with a very gentle inclination on either side, the beds of coal ending smoothly and gradually against it.—(See *Mems. Geol. Survey*, S. Staff., 2d edition.) Its formation was obviously anterior to that of the coals which it "cuts out;" those coals and the "swell" itself being regularly covered either by a higher bed of coal, or by the "roof" of the seam, without any interruption or disturbance. The swells are

* A very pretty little machine has been invented by Mr. Sorby for producing this oblique lamination. Sand poured into a small trough is carried forwards by means of a screw, and falling down into a narrow space between a board and a sheet of glass, arranges itself in inclined layers according to the rapidity with which the screw is worked and the angle at which the instrument is held.

sometimes 200 or 300 yards long, and 10 or 12 yards wide at the base (See fig. 14.)

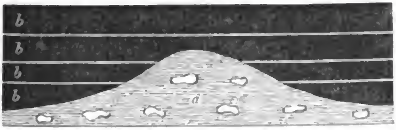


Fig. 14.

In this Fig. *a* is black clunch containing balls of ironstone; *b b*, beds of coal.

Current Mark or Ripple.—Another effect of current is to produce a "ripple" or "current mark" on the surface of a bed of sandstone or sandy shale. This rippled surface is exactly the same as that which is seen on the sands of the sea-shore when left dry by the tide, and which may occasionally be seen at the bottom of any clear water where a current is moving over sand. It may be observed also sometimes on sand-hills on dry land, where it is produced by the drifting action of the wind. Either wind or water, as they roll before them the little grains of sand, tend to pile them into small ridges, which are perpetually advancing one on the other, in consequence of the little grains of sand being successively pushed up the windward or weather side of the ridge, and then rolling over and resting on the lee or sheltered side.

It is produced on the sea-beach, not in consequence of the ripple of the wave impressing its own form on the sand below, which would be an impossibility, but because of the moving current of water as the tide advances or recedes. Wind moving over the surface of water causes a ripple on that surface. Wind or water moving over the surface of fine incoherent sand causes a similar ripple upon it. The ripple on the surface of the water is quite momentary, since the perfect mobility of the particles of a liquid among each other causes them to tend to arrange themselves so as to produce a level surface the instant the lateral impulse is withdrawn. The ripple on the surface of sand, however, remains when the lateral pressure of the water or air current ceases to act, and is permanent unless obliterated by some subsequent force.

If the rippled surface be covered by the tranquil deposition of a film of clay, or if it acquire some degree of consolidation before another layer of sand be blown or drifted over it, it may remain fixed for ever. In fine grained sandstones, it is not unusual to find many successive rippled surfaces, one under the other, at spaces of some inches or some feet apart vertically.

It is clear that the under surface of the layer of sand which is

deposited upon a rippled surface will itself take a cast of the rippled form, and when the two surfaces are removed, and placed side by side, it may not always be easy to say which was the original ripple and which its cast.

In like manner, when beds having rippled surfaces have been tilted up naturally into a vertical position, or pushed beyond that so as to be partially inverted, it may not be easy to say which surface was originally the upper and which the lower. Sometimes, however, this can be ascertained either from the form of the ripple itself, or from other markings, and the character occasionally becomes of value as assisting to prove the fact of inversion.

The existence of a rippled surface is no evidence of itself as to the depth of the water in which it was formed. A current of water of any depth whatever, which pushes grains of sand along the bottom, may produce a rippled surface on that sand. The ripple on the surface of water, or on that of dry sand-hills, is produced at the bottom of the atmosphere, and if the lower stratum of deep water, no matter what the depth might be, moved in like manner, it would produce a similar effect. Rippled surfaces will, however, be more frequently produced at the bottom of shallow than of deep water, because the requisite currents are more frequent in the former than the latter.

The size of the ripple, or the distance from crest to crest of the ridges, varies from half an inch to eight or ten inches, with a proportionate variation in the depth of the hollows between them. Sandstones of all ages, from the oldest known rocks to the most modern, have occasionally rippled surfaces. Magnificent examples are sometimes shewn in the cliffs of the south-west coast of Ireland, where highly inclined beds are sometimes seen bared in the face of the cliffs at the sides of small bays or coves, exposing most beautifully and symmetrically rippled surfaces over an area of a hundred or two hundred feet in diameter.

Mr. Sorby has shewn that inferences may be drawn from the examination of these "current-marks" as to the strength and direction of the currents that caused them, and that we may thus reason back to some conclusions as to the physical geography of particular districts in former geological periods.

In places where the current was troubled and confused, a modification of these rippled surfaces is sometimes produced, the bed being irregularly mammillated on its surface, which is pretty equally, although irregularly, divided into smaller hollows and protuberances of a few inches diameter. This surface structure may be seen in process of production now, on shores where spaces of sand are enclosed by rocks, so that as the tide falls it is made to run in different directions among the rock channels ; but it would probably be caused at any depth at which a current could be similarly troubled and confused. It is not

unfrequently seen among gritstones, even those of the very oldest rocks. It might be called "dimpled current-mark."

A conclusion of some importance to geological theory may be derived from these, as from other physical structures in rocks, namely, that the strength, velocity, and mode of action of moving water in the old geological periods was precisely of the same kind and intensity as those with which we are familiar at the present day.

Contemporaneous Erosion and Filling up.—Stratified rocks sometimes occur in such a way with respect to each other as to shew that a bed, not only of sand, but of clay, coal, or other soft rock, after being formed, has had channels or hollows cut into it by currents of water, and these hollows have been filled up by a part of the bed next deposited.

In fig. 15, taken from a road cutting in the New red sandstone at Shipley Common, near Wolverhampton, 1 is a bed of red and white

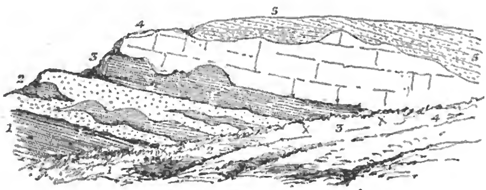


Fig. 15.

marl or clay; 2 is a chocolate brown sandstone with irregular beds and patches of marl; 3 is a bed of red marl, like 1, but which seems at one time to have been thicker than it now is, and to have had some part of its upper surface carried off before the deposition of 4, which is a brown sandstone, that in like manner seems to have had its upper surface eroded and the hollows filled up by the deposition of 5, which is a mottled, red brown and white, calcareous sandstone, or cornstone.

This erosion sometimes affects even a small group of beds. In the tertiary beds near Paris, which are believed to have been deposited in a shallow bay or gulf, receiving rivers, and therefore traversed by currents, this structure is frequent. Two remarkable examples were observable in the large excavation near the terminus of the Rouen railway. In a cliff about 40 feet high in the fresh-water limestone formation, called the Calcaire St. Ouen, two trough-like hollows were seen about 50 yards apart; the beds previously formed having been excavated for a depth of 20 feet and a width of 15, and the hollows thus formed being filled

up by irregular meniscus-shaped* expansions of the upper beds. (See fig. 16.)

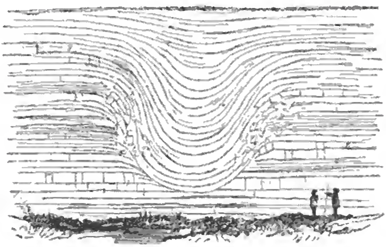


Fig. 16.

Hollow of erosion in tertiary rocks near Paris, filled up by thickening of the subsequently formed beds.

I am not aware whether the French geologists believe that any considerable geological period elapsed between the deposition of the beds thus eroded and those which fill up the hollows.

Similar trough-like hollows are met with in coal mining, traversing beds of coal, the coal being eaten away, and the hollows filled up by the matter which compose its roof, such as clay, shale, or sandstone. Mr. Buddle has described very fully one met with in the Forest of Dean, where the miners gave the name of "the horse" to the stuff which thus seemed to come down and press out the coal. This trough was found to branch when traced over a considerable area, as in coal mining it necessarily was, and to assume all the appearance of having been formed by a little stream with small tributaries falling into it ; the channels of the stream being afterwards filled up by the subsequently deposited materials that were spread over the whole coal.—(*Trans. Geol. Soc. Lond.*, vol. vi. n. 3.)

Another modification of this erosive action is represented in Fig. 17, taken from a sketch made in a quarry in the neighbourhood of Hobart Town, Tasmania, where a bed of soft brown unctuous clay, about a foot thick (*b*), lying between two beds of hard white sandstone (*a* and *d*), suddenly ended, and its place was occupied by sandstone (*c*), similar in character to the beds above and below it. We must in this case suppose that after the formation of the bed of sandstone (*a a*), a bed of clay (*b*) was deposited over a certain portion of the area, and that then a current of water, bringing in sand, wore back the little bed of clay, eating into it so as to form a small cliff or step, and depositing the

* A meniscus is a lens concave on one surface, and convex on the other, the surfaces meeting, which those of the beds do sometimes.

sand (c) afterwards against it, as represented in the diagram. The two beds, thus exactly on the same level, but *not exactly contemporaneous*, were finally covered by the bed of sandstone (d d), which spread equally over both of them.

We see in this case proof, that although the bed c is exactly on the

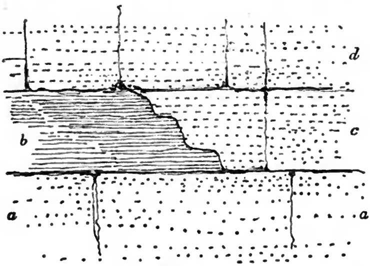


Fig. 17.

Eroded termination of bed of clay, with sandstone formed against it (Hobart Town, Tasmania).

same level as the bed b, both reposing on, and both covered by, the same beds, yet they are still not exactly of the same age, but that c was formed subsequently to b, inasmuch as b was not only formed, but partially destroyed, previously to the formation of c. Such facts give us farther proof of the length of the intervals which may elapse between the formation of two beds, such as a and d, and also caution us not in all cases to infer strict synchronism from the fact of beds occupying the same geological horizon.

Contemporaneity of Beds on same Horizon.—If a group of beds, whether large or small, have the arrangement shewn in fig. 18, the

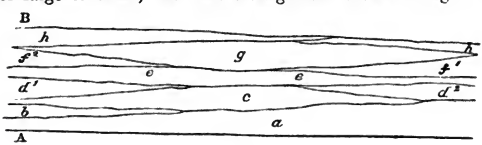


Fig. 18.

order of the formation of the beds is clear enough as regards a, b, and c; but d^1 and d^2 may either have been deposited contemporaneously, or one before the other; e is clearly subsequent to them both; but the relative age of f^1 and f^2 is uncertain, while there is no doubt about that of g and h. If we wished to estimate the whole time consumed in the formation of such a

set of beds, it would be obviously wrong merely to take their mean thickness, as shewn at A B, for the measure of that time. The whole thickness of *a* had been deposited before *b* had been begun, and both were complete before *c* was formed. If, therefore, we assume thickness, or quantity of material deposited, as the measure of time occupied in deposition, it is clear that we should add together the maxima of *a*, *b*, *c*, and not take their mean ; and in doing this, we should feel some doubt as to whether we ought not to reckon d^1 and d^2, and similarly f^1 and f^2, as two separate and consecutive beds, instead of supposing them to have been formed at the same time.

The more carefully we study the stratified rocks, the more extensive become the periods of time we have to allow for their formation, and the more numerous and longer are the intervals of non-deposition that occur to us.

Interstratification, Association, and Alternation of Beds.—No general rule can be laid down as to the association of different kinds of beds with one another. Limestones, sandstones, and clays occur either in separate groups, or interstratified one with the other in every imaginable variety of disposition.

We have sometimes a series of beds, many hundreds of feet in aggregate thickness, of pure limestone, with scarcely a single seam of clay or sand, even so much as an inch thick. Instances of this are shewn in the Chalk of the south-east of England, and the Carboniferous Limestone of Derbyshire, and of large portions of Ireland.

In the case of the Chalk, there is in some places a thickness of as much as 1000 feet of soft, almost powdery, and nearly pure, white, carbonate of lime, that looks more like an artificial than a natural product. Its stratification even is occasionally indistinct, as if there had been almost a continuous deposit of this material with scarcely any interruption, though this is probably the result of the comparatively slight consolidation of the rock rather than of its rapid accumulation.

In the district called Burren, in county Clare, there are hills more than 1000 feet high, exposing slightly inclined beds of Carboniferous limestone perfectly bare of soil, or any other covering, from their summits down to the sea. A thickness of 1400 feet, at least, is thus shewn without a trace of any other bed than pure gray limestone.

Series of beds of sandstone, almost entirely devoid of calcareous or argillaceous matter, and having a total thickness of many hundred feet, likewise frequently occur. Old gravel beds, now compacted into conglomerate, are often associated with these ; and the sandstones exhibit every variety of texture, from lines of small pebbles to the finest possible grains. In such masses of sandstone, it is rare to find any foreign bodies, and mineral concretions or chemical deposits hardly ever occur in them.

Groups of beds of almost pure clay also occur, making up a total thickness of several hundred feet, with hardly a single bed of sandstone or limestone to be found in them.

While cases of this accumulation of one particular kind of matter, of great thickness, are by no means rare, it is perhaps more usual to find different beds of rock alternating one with the other, sometimes so interstratified that there is never a greater accumulation than twenty or thirty feet of any one sort without others interposed between them.

Beds of limestone are frequently separated by beds of clay or shale, which is most commonly black or brown. These shales are themselves sometimes calcareous, and there seems occasionally to have been such an equal mingling of the two kinds of matter, that it is hard to say whether it would be most proper to call the rock a shale or a limestone. Such are some of the beds known as calp shale or calp limestone in the middle districts of Ireland.

Beds of sandstone, again, often alternate with such shales, so that we get a series of beds consisting of alternations of all these kinds. Beds of limestone sometimes alternate with sandstones, some of which may likewise be calcareous; but it is more rare to find pure limestone and pure sandstone interstratified with each other, than to have clayey beds alternating with either or with both. Speaking generally, indeed, we find, in examining the vertical succession of beds of rock, an approach to the same kind of passage or gradation that we sometimes perceive in their lateral extension. Beds of very fine and very coarse materials rarely rest directly one upon the other. Conglomerates are generally covered and underlaid by sandstones, and not by clays or shales. Coarse sandstone, in the same way, has usually a bed of finer sand, either above or below, before shale or clay occurs.

The transition from the conditions favourable to the deposition of one kind of rock to those conducive to another has generally been gradual rather than abrupt. The tranquil water of the open sea, which seems to be the general producer of limestone, becomes first invaded by gentle currents, bringing in finely suspended mud, before it is traversed by those of sufficient strength to carry out the coarser material of sand. Not unfrequently, however, alternations of finer and coarser grained laminæ occur even in the same bed, proving that the bed was formed by a succession of actions, and by as many different deliveries of matter into the water as there are sets of alternations.

It will be well perhaps to give here a few instances of alternation of beds, taken from actual observation and measurement. The first is from Phillips's *Geology of Yorkshire*, vol. ii., p. 66.*

* In all tabular lists of beds or formations in this work, the series will be arranged on the page in their order of superposition, but they will be numbered in order of age, beginning with the oldest or first formed.

No.		Feet.
21.	Beds of sandstone, called Millstone Grit, together	87
20.	Beds of shale, taken together	30
19.	A bed of limestone	2
18.	Beds of shale	18
17.	A bed of limestone	3
16.	Beds of shale	6
15.	A bed of limestone	3
14.	Beds of shale, together	25
13.	Flinty chert (a compact siliceous rock)	16
12.	A bed of shale	1
11.	Crow chert. (Crow is a local term)	6
10.	Shales	9
9.	Second crow chert	12
8.	Crow limestones (probably in several beds)	12
7.	Sandstone or gritstone	6
6.	Coal	1
5.	Sandstone or gritstone	7
4.	Shales	8
3.	Gritstone in several beds	88
2.	Girdles (a kind of sandstone)	10
1.	Shales	18
		368

These beds are grouped together, with some others, under the name of the "Millstone grit series," by Professor Phillips, it being often necessary to supply some one designation to a complicated series consisting of all kinds of rock.

In sinking coal pits, many alternations of arenaceous and argillaceous rocks, the latter often containing ironstones, with different varieties of coal, are almost invariably met with. The following is an example derived from the Bristol coal-fields (*Mem. Geol. Survey*, vol. i., p. 210).

No.		Feet.	In.
23.	Argillaceous shales	185	0
22.	Sandstone	4	0
21.	Coal	1	6
20.	Underclay	2	0
19.	Argillaceous shales	64	0
18.	Coal and shale	4	0
17.	Coal	1	0
16.	Underclay	4	0
15.	Argillaceous shale	4	0

No.		Feet.	In.
14.	Sandstone	2	0
13.	Argillaceous shales	23	0
12.	Coal	9	0
11.	Underclay	3	6
10.	Coal	0	6
9.	Underclay	2	0
8.	Argillaceous shales	7	0
7.	Sandstone	1	0
6.	Argillaceous shale	2	0
5.	Sandstone	6	0
4.	Argillaceous shale	4	0
3.	Coal	2	4
2.	Underclay	2	0
1.	Sandstone	3	0

The whole section of which this is a portion, enumerates 294 similar alternations, having a total thickness of 5084 feet, with an additional series below, 1200 feet thick, principally composed of hard sandstone.

It may be useful to add another section from a totally different set of rocks, but still exhibiting the same facts as to the alternation of various kinds of beds. It was taken at Catsgrove Hill, near Reading (Conybeare and Phillips, p. 43).

No.		Feet.
12.	Soft loam	11
11.	Dark red clay, mottled with gray	4
10.	Light ash-coloured clay, mixed with fine sand	7
9.	Fine micaceous sand, laminated, partially mixed with clay	4
8.	Fine ash-coloured sand	5
7.	Dark red clay, mottled with blue	6
6.	Light gray clay, mixed with fine sand	5
5.	White sand	4
4.	Fuller's earth	3
3.	Yellowish quartzose sand	5
2.	Siliceous sand, with rolled and angular chalk flints	3
1.	Chalk to an unknown depth.	

It is to be specially noted, as regards the occurrence of coal, that it almost invariably rests on a fine argillaceous bed, often what is called "fireclay." This fact is familiar even to the miners, so that it has received the name of "underclay" in the South Welsh district, and in others, as in the South of Ireland, is called "coal *seat*." The general order of superposition (or of time of formation, for these are convertible

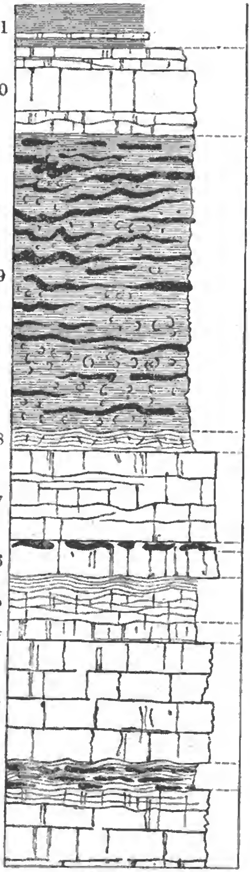


Fig. 19.

	Ft.	In.
11. Earthy rotten shale, with a thin hard band	2	7
10. Gray crystalline crinoidal limestone . .	3	4
9. Soft brown earthy shale, with abundance of fossils and many irregular layers of black chert . .	11	6
8. Hard gray shale with encrinites and shells	0	9
7. Gray compact limestone	3	6
6. Do. with layer of black chert nodules . .	1	4
5. Thin irregularly bedded limestone, with shale at top . . .	1	9
4. Compact limestone .	0	9
3. Light gray compact limestone . .	4	8
2. Black chert layers in hard black shale .	1	0
1. Gray compact limestone forming floor of quarry	1	0
	35	2

terms), is 1. Sandstone; 2. Clay; 3. Coal; 4. Clay. If we disregard the minor alternations, we should see this rule carried out in almost all sections of Coal-measures, the clay above the coal (the roof) being generally thinner and stronger (more shaly) than that immediately below. In some few instances the coal seat is arenaceous, and still more frequently a sandstone or "rock" roof may be found.

The section (fig. 19), supplied by Mr. G. V. Du Noyer, represents the top beds of the Upper Carboniferous limestone of Ireland, where they pass into the lower Coal-measures. It was taken in a quarry near Old Leighlin, County Carlow.

The foregoing sections will shew the student the way in which beds of aqueous rocks are frequently interstratified one with another, and how minute are sometimes the subdivisions of the beds, and how frequent and sometimes rapid their changes when examined in vertical succession.

Included Group of Beds (Inlier).—It occasionally happens that one large series of beds having a common character includes in some part of it a small distinct set of beds with a peculiar character of their own. The Germans use the word "einlager," which means "being billeted, quartered, or lodged in a place," and may sometimes apparently be translated by our word "inmate," to denote such a set of included beds.

Our word "inmate" is only applicable to persons, and I have not been able to think of any other term than "inlier" to describe a set of beds that are included within the general boundaries of another larger set. We may thus speak of the Bala and Hirnant Limestones as being inliers of the Bala series; of the Bradford Clay and the Fullers' earth as inliers of the Lower Oolites. It appears to me that such a term is wanted, and would often conduce to a truer appreciation of the value of the different terms of the geological series.

Lateral Change in the Lithological Characters of Beds.—It has been already shewn that every bed must necessarily thin out and terminate somewhere on all sides, and it has also been shewn that beds lying side by side on the same horizon are often different in lithological composition. What is true of one bed may be true of sets of beds, so that, while the whole of a set of one kind of beds may in one direction be replaced by a set of a similar kind, in another the replacing set may be of a totally different kind of rock.

We might, for instance, in one locality, have a series of limestones, resting one upon the other, without the intervention of any other beds. As we traced this group across a country, we should perhaps find that little "partings" of shale began to make their appearance between some of the beds of limestone, and that as we proceeded these shales became thicker and more numerous, while the limestones became thinner in

proportion. Some of the limestones would perhaps then altogether disappear, and the shales themselves would be partially replaced by beds of sandstone, until at length we should find our series consist almost entirely of sandstones and shales, with only one or two very subordinate beds of limestone, perhaps to represent the purely calcareous group with which we commenced. The diagram, fig. 20, gives a rough representation of this lateral change, but requires to be drawn out to twenty or thirty times its length before it could be taken as a proximate delineation of the facts as they occur in nature.

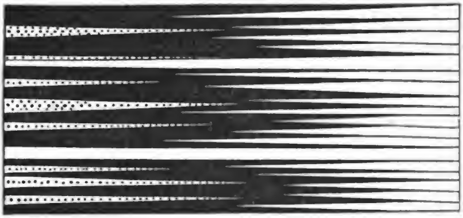


Fig. 20.

In this diagram the white bands are meant for limestones, the black for shales, and the dotted for sandstones.

In the same way, groups that consist principally of sandstone and conglomerate in one district may in another be composed chiefly of limestone and shale or clay, with or without any beds of sandstone.

The scale upon which these lateral changes of character are carried out is altogether indefinite. We see it sometimes take place with respect to a small group of beds within the limits of a single quarry; in other cases, a distance of a few hundred yards or a few miles is requisite before the alteration is apparent. Some groups of beds, indeed, preserve their mineral characters but little altered over whole countries or across whole continents. Still, judging from what we know, we must always hold ourselves prepared for change even in the rocks that seem most constant in their characters; and as a matter of fact, we know of no one group of aqueous rocks that preserves the same mineral characters in all parts of the earth.

We have many excellent examples of these lateral changes in groups of strata within the limits of the British islands. We can perhaps hardly instance a more characteristic one than that afforded by the group of beds known as the Lower Oolites, which are readily traceable in one continuous ridge from Somerset, through the centre of England

to the Humber, and reappear again as high ground in the north of Yorkshire. These beds repose upon some dark shales and clays known as the Lias, and are covered by a thick mass of clay called the Oxford Clay. These two thick groups of clay are equally traceable across England, so that the beds which lie between them must almost necessarily belong to the same formation, or, as it is sometimes expressed, lie on the same geological horizon, whatever may be their lithological characters, and even if they are not themselves traceable continuously. The Lower Oolites, which thus lie between these two great clay deposits, consist, in the south of England, very largely of oolitic limestones, and it was here they received their name of "The Oolite," while in Yorkshire the limestones are replaced by sandstones and clays, with beds of coal, and the thickness is considerably greater than in the south. The section of the two groups may be described as follows :—

Gloucestershire, etc.

			Feet.
Oxford clay.			
5.—Cornbrash			16
4.	Clay	11	91
	Calcareo-siliceous sand	10	
	Forest marble	18	
	Sand	2	
	Clay	50	
3.—Great oolite			130
2.	Blue Clay	14	122
	Fuller's earth	8	
	Bastard Fuller's earth, with a band of shelly sandstone	100	
1.	Inferior oolite	30	80
	Calcareous sand	50	
	Total		469
Lias			

Yorkshire.

		Feet.
Oxford clay.		
5.—Cornbrash		5
4.	Sandstones and shales, with ironstone and coal	190
3.—Gristhorpe oolite		15
2.	Sandstones and shales, with ironstone and coal	450
1.	Yellow and gray micaceous and ferruginous sandstone	70
	Total	760
Lias		

The Gloucestershire section is taken from Conybeare and Phillips' Geology of England and Wales, and that of Yorkshire from Professor Phillips' Geology of Yorkshire, with which has been compared his paper on the Oolite and Ironstone series of Yorkshire in the Journal of the Geological Society of London, vol. xiv., p. 84.

Still greater changes take place in the lateral extension of the larger group of rocks known as the Carboniferous formation, when traced from Devonshire and Cornwall through the centre of England into Scotland, as will be seen farther on when we come to describe the typical rocks of that formation.

A great change also takes place in the group of beds called the Old

Red Sandstone, as we trace them east and west across Ireland, from Wexford and Waterford into the counties of Cork and Kerry.

If the diagram, fig. 20, be supposed to represent a series, not of individual beds, but a series of formations, so that each of the divisions be supposed to be many hundred feet thick and many miles in extent, they will equally represent, in a rude manner, the way in which the stratified crust of the earth is made up. No single bed, no group of beds, no series of beds, no formation, is of unlimited extent. They all come to an end somewhere; having, at their first formation, by the very conditions of their production, gradually diminished and died away in every direction from some local centre or centres of deposition.

Nomenclature of Groups of Beds.—It may be asked here if the lithological characters of groups of beds be so variable, how is it that geologists identify rocks by the same designation all over the globe? How is it that we speak of Silurian, or Cretaceous, or Tertiary rocks in Australia, in Africa, in Asia, and in America, as well as in Europe? The answer is, that geological terms, when applied to rocks in this sense, have a purely chronological signification; they refer to periods of time; they mean that the rocks called Silurian, for instance, in Australia were formed at the same time, or during the same great period of the world's history, as those which are called Silurian in Siluria. How this is proved will be shewn further on; but it is necessary here to warn the student of this meaning, in order that he may not form erroneous notions.

Just as we may suppose earthy depositions to be now taking place in Bass' Straits, for instance, as well as in the English Channel, so we know that mineral matter was deposited contemporaneously here and there upon the earth at all periods of its history since land and water came into existence upon it. If by any process of reasoning or investigation we can find out those rocks which were simultaneously formed, or nearly so, it is obviously advantageous to designate them by a common name, simply to point out the fact of this similarity in age, without inferring that they were ever parts of a continuous mass, or were formed of the same materials, or were produced exactly in the same way, or under precisely similar conditions.

Now, whatever may be the origin of the name we adopt, whether it be that of their lithological character at the locality where they were first described, or whether it be derived from some mineral substance contained in them, or from the place where they are best seen, or any other source, we must be careful to recollect that the name will in many cases be a mere name and not a description, since its original meaning can never be universally applicable. Just as we find Mr. White and Mr. Black, Mr. Long and Mr. Short, with persons the very reverse, perhaps, of what their names would imply, so we may in

geology have the name of "red" or "green sandstone" affixed to rocks which in some places are neither red nor green, nor even sandstone, so we may have "coal-measures" which in some places contain no coal, and "chalk" or "cretaceous" rocks which, in some parts of the world, consist of black marble, of brown sandstones, or of dark clay-slate.

Lateral and Vertical Changes in Groups of Beds, the natural result of their Mode of Formation.—The apparent contradiction that arises between the signification of the name of a group of beds and their lithological character is often a difficulty in the way of a beginner; but when he comes to reason on the modes of formation of stratified rocks, he finds it much easier to explain their variable character by reference to the present course of nature, than he would to account for their invariability if each formation retained everywhere the same lithological character. It is easy to understand both the fact of a formation retaining a similar lithological character over one very large area, and that of its frequently and rapidly changing that character over another area, by referring to what we know to be taking place on the earth at the present day.

If we compare the bottom as indicated in the charts of the British islands and the west coast of Europe, or those of Newfoundland and the east coast of America, with the bottom of the central portion of the Atlantic, as shewn by the soundings taken for the Atlantic telegraph (see *ante*, p. 128), we shall find one widely-spread uniform deposit of sticky oaze, like chalk, taking place in the ocean, with little or no change, over spaces more than 1000 miles across, while the change from this to the sands and muds as we approach the coasts is sudden, and the changes in the nature of the shore deposits are both frequent and rapid. Yet all these deposits are taking place contemporaneously, and would, if the bed of the Atlantic were elevated into dry land, be almost necessarily grouped together under one name.

In the great Pacific Ocean, we may be sure that deposits are taking place, derived from the waste of the vast number of coral reefs, having a constant character over an area quite as wide as any of the formations we are acquainted with on dry land. This great formation may not be absolutely continuous even over all that part of the ocean in which the coral reefs occur; but beds of precisely identical mineral character, and containing almost exactly the same organic remains, will be spread over large areas round several central points, where they will probably be thickest, and from which they will thin out in every direction. Some of these areas of deposition of limestone may perhaps overlap each other, while others will be separated by clear spaces of sea bottom, where probably no deposition is taking place, or by other sea bottoms, where sediment is deposited of altogether a different character from that derived from the coral reefs. All the great rivers of Eastern Asia, for instance,

such as the Hoang-ho and Yang-tse-ki-ang, which pour their turbid waters primarily into the Yellow Sea, and the great river Amour, which falls into the sea of Okotsk, as well as those of California and the north-west coast of America, carry down earthy materials into the Pacific of a totally different character from the coral-reef detritus ; and some of this may be very widely spread, and form large deposits on both sides of the Pacific. If we could suppose fine sediment derived from two such different sources to be so far diffused through the water as to overlap, now one sort thrown down, and now another, with an occasional admixture of both, we should have exactly the conditions necessary for such contemporaneous formations of one kind of rock in one locality, and another kind in another district, with intermediate areas affording alternations of the two, as we find in the great formations composing the existing lands of the globe.

If we pass from the great Pacific into the China Sea and the northern part of the Indian Ocean, where coral islands are mingled among active volcanoes, both aerial and submarine, and into which open the mouths of vast rivers, draining a great continent, we know of no variety of rock and no combination of mineral matter that has ever been observed upon earth that we should not feel warranted in believing to be possibly in course of production within the area. All these different kinds of rock would be of contemporaneous formation, although of different mineral character, and they would enclose the remains of many animals and plants of the same species throughout, or of species so nearly allied as to shew that their variations depended chiefly on the geographical distribution of organic beings inhabiting different parts of the globe at the same time. If elevated into dry land, then, they would, by the rule now followed by geologists, be grouped together as one "formation" under some one common designation.

CHAPTER X.

JOINTS.

Formation of Rock-blocks.

We could not long study the lamination and stratification of aqueous rocks, and observe their separation by those planes of division, which are obviously the result of distinctness and succession in the acts of deposition, without being struck by the occurrence of other planes of division, which cut the first at various angles, and assist them in dividing the rocks into regular or irregular blocks.

We should, indeed, very soon perceive that *all* rocks, stratified or unstratified, igneous, aqueous, and metamorphic, are traversed by numerous planes of division of this kind. They may be seen in any quarry, or in any natural or artificial excavation in any solid rock, traversing the rock in various directions, and separating it into blocks of correspondingly various shapes and sizes.

These divisional planes are called JOINTS.

Without natural joints the quarrying of stratified rocks would be very difficult, and that of unstratified rocks almost impossible. If beds of sandstone or limestone were undivided by natural joints, each block would have to be cut or split by artificial means on every side from the rest of the bed; but in rocks, such as granite or greenstone, which have no beds, the blocks would not only have to be cut away on each side, but *underneath* also. It would obviously be a most impracticable task to *dig out* a large block of granite from the midst of a solid mass untraversed by any natural planes of division of any kind.

Cuboidal or Quadrangular Joints.—For the production of natural blocks of rock there must clearly be, *at least*, two sets of joints in stratified, and three sets in unstratified rocks, each set more or less nearly at right angles to each other. (See figs. 21 and 22).

If we compare a set of stratified rocks to a pile of slices of bread, it is clear that to divide these into lumps, we must cut them in two ways, lengthwise and across. The unstratified rocks, however, would resemble the whole loaf, which we must cut at least in three directions in order to divide it into lumps, first horizontally into slices, and then lengthwise and across.

In addition to these fewest possible sets of joints in the two kinds of rock, there are in reality others in various and irregular directions; but inasmuch as three planes of separation more or less nearly at right angles to each other are the essential conditions for the separation of rock into blocks, and as three equidistant planes at right angles to each other would form cubes, we may speak of joints thus forming quadrangular blocks as *cuboidal* or *quadrangular* joints, to distinguish them from those which produce prisms, and we may look upon three-cornered and irregular blocks as merely portions of cuboidal ones.

Figure 21 is a sketch taken by Mr. G. V. Du Noyer, in a limestone quarry near Mallow; in which the parallel lines, nearly horizontal but

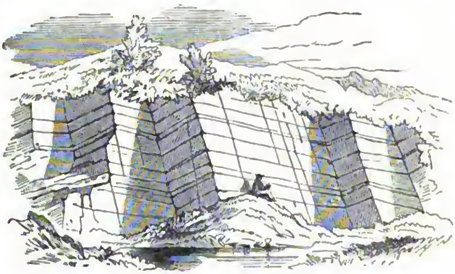


Fig. 21.
Joints in limestone. Quarry near Mallow, county Cork.

inclining gently from the spectator, are the planes of stratification, while the smooth nearly vertical surfaces, which form the face or wall of the quarry and bound the projecting corners of rock, are the joint planes. One set of these joints runs lengthwise through the quarry, and makes the successive surfaces on which the light falls; the other set forms the dark surfaces which are at right angles to the light ones, and other joints belonging to this set are shewn by the nearly vertical lines which are seen upon those light surfaces, those lines being the edges of joint planes.

Figure 22 is from a sketch taken by Mr. Du Noyer, in the large granite quarries from which the stone to form Kingston harbour was extracted. It will be at once apparent that this rock exhibits no regular beds. One set of parallel planes of division, highly inclined to the right, seems to prevail in one part of it, and another set, highly inclined to the left, in another part. These might at first, perhaps, be in each case taken for planes of stratification, and the pieces of rock

between them be considered to be beds. They are, however, merely two sets of joints, and they are crossed by a third set producing the shaded faces of rock which front the spectator. In walking about the

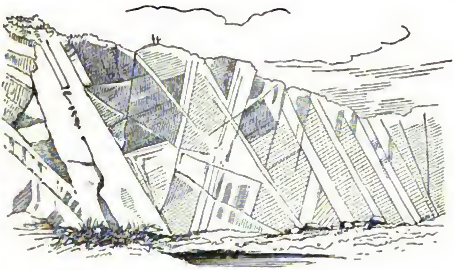


Fig. 22.

Joints in granite. Large quarries in Killiney Hill, near Dublin.—G. V. D.

quarry each of these three sets of joints becomes most conspicuous, according to the point of view which may be taken; while they are sometimes all masked or obscured by a number of other irregular joints which cut the mass in many other directions.

Master Joints.—There is, indeed, in all rocks, whether aqueous or igneous, a distinction to be drawn between the "master joints" or those large planes of division which run regularly parallel to each other over large distances, and the numerous smaller joints which often traverse the rock in all directions, and sometimes separate it into indefinitely small angular fragments. This distinction is, however, one which it is often difficult to point out, since there are many joints of intermediate character.

Sometimes, indeed, in aqueous rocks the joints are so numerous, and cut the rocks in so many directions, that the original planes of stratification are altogether obscured by them, and it is impossible to say, among the numerous planes of division, which are those of the original separation between the beds, and which are those of subsequent origin.

There are cases, on the other hand, of joints a few feet apart cutting in parallel lines through whole mountain masses, the space between two nearly adjacent joints being eroded into a deep fissure, so as to produce a more marked feature in the hills than their planes of stratification. Such remarkable joints are very strikingly exhibited in the mountain ground between Bantry and Kenmare bays, in the south-west of Ireland.

There must in some cases either be great width between the planes of one particular set of joints, or one set must be more or less completely absent, so that, in one direction, the rock is unbroken for considerable distances. This must be the case with the rocks from which the great monolithic pillars were extracted in the old Egyptian and other quarries.

I have myself observed on the shores of Newfoundland large exposures of granite, in which only one set of perpendicular joints was apparent, and those having a width of several yards between them, and running parallel for considerable distances. It appeared as if thick monoliths of almost any length might have been procured there.

While the surfaces of a block formed by the joints always approximate to planes when viewed on the large scale, they are nevertheless sometimes very uneven, and sometimes even curved. I have observed in a limestone quarry near Foynes, a master joint that formed a surface as much curved as the side of a ship, only waving backwards and forwards in length, so as to curve now on the one side and now on the other of the perpendicular.

Open or close Joints.—Joints are generally close, regular, and symmetrical, in proportion to the fineness of the grain and the compactness of the rock, being most irregular and uneven in coarse sandstones and conglomerates. The power of the force which produces them is, however, well shewn in hard and well consolidated conglomerates, since the hardest pebbles of pure white quartz are often cut as clean through by the joints as the compacted sand in which they lie. In sandstones, joints are frequently open; in shales, they are closer, but more smooth and regular, being frequently perfect planes, with the sides of the blocks fitting close together. In limestones, there are both close and open joints; but the open joints have frequently been widened by the action of water percolating through them, and dissolving a portion of the rock. Great fissures are sometimes formed in this way; and this has doubtless been the origin of many of the caverns which occur so abundantly in limestone rocks. In highly argillaceous limestones, however, the joints are often beautifully smooth, regular, and close.

Successive formation of Joints.—In stratified rocks, it often seems as if each bed had a system of joints formed before the other was deposited upon it, inasmuch as the joints formed in one do not penetrate the other. There are, however, always other joints common to a whole set of beds, and produced apparently in the whole simultaneously. It is not uncommon for joints, in passing from one bed to another, to shift a little, or slightly change their angle. In such cases it may be doubtful whether a joint previously formed in the one bed may not have given rise to the formation, or at least have modified the position, of the other, in the bed above.

Joints in Burren, County Clare.—No country in the world, perhaps, affords equal facilities for studying cuboidal joints with the barony of Burren, in the northern part of the county of Clare. Hills of limestone rise more than 1000 feet above the sea, with the beds almost horizontal, the summits of the hills and the terraces that sweep round their sides shewing broad floors of bare rock over the whole country. The joints, which are very numerous and very regular, have been widened by the rain, so as to form superficial crevices, sometimes several inches in width and several feet in depth. The floors of limestone are cut by them into a number of separate blocks of quadrangular and triangular forms. Mr. Foot, of the Geological Survey, with whom I lately visited the district, pointed out to me that there were three distinct sets of joints besides other irregular ones. By far the most regular, persistent, and frequently occurring of these were planes running about N. 5° or 10° E. These were crossed by joints running about N. 30° or 35° E., producing very curious sharply-angular vertical wedges of limestone between the two. Nearly at right angles to the plane which would bisect the angle between these two, that is, about E 20° or 25° N., was another very frequently occurring set of joints, but these were much more interrupted and discontinuous than those of the first-mentioned sets. Many others cut obliquely across all, very irregularly and uncertainly.

I observed, with respect to the first-mentioned set, that sometimes the neighbourhood of one joint plane, or the space between two if they happened to be within a yard or so of each other, exhibited a number of closely adjacent minor parallel joints not more than an inch or so apart, splitting the beds across into vertical slabs. It is probably to the production of these minor joints, which almost approximate to "cleavage" in their mode of occurrence, that the long parallel crevices are due which were mentioned just now, as remarkable about Bantry Bay and other places, the slabs having been weathered out.

In one place, a few miles south-east of Ballyvaghan, the gently undulating surface of a bed was exposed over an area half a mile wide, which was traversed by long regular vertical joints running at various angles from N. 4° W. to N. 7° E., cutting each other at angles sometimes of not more than 3°, and running in straight lines for several hundred yards.

These joints were crossed by others running nearly east and west, not in straight, but in regularly gently-curved serpentine lines. The straight north and south joints sometimes stopped suddenly at one of these cross joints, and then set on again after an interval of a few yards in the same line. The union of square, sharply triangular, and curved-sided blocks, with deep fissures between them, the surfaces and edges of the blocks being curiously rounded and channelled by the rain into ornamental fret work, as if the white limestone were ice rapidly

melting, produced a most singular scene, to which beauty was added by the magnificent ferns and other plants growing in the crevices of the joints, which seemed to act as natural conservatories to protect the vegetation from rough weather.

Face, Slyne, or Cleat in Coal.—Beds of coal exhibit not only large distant joints, like all other rocks, but a more minute structure dividing the mass of the coal into small cuboidal lumps. This structure may be observed in any lump of coal taken from the coal hod.

The coal splits most easily and readily along the lines of lamination or stratification, or "with the grain," as it would be commonly expressed. The surfaces thus exposed on the tops and bottoms of the lumps are generally dull and earthy, and readily soil the fingers. At right angles to these surfaces others may be observed which are generally bright and shining, and if the coal be freshly broken, these surfaces soil the fingers much less than those on the top and bottom of the lump. The bright surfaces which cut vertically across the grain or bedding of the coal are generally at right angles to each other, so as to make a number of square corners, and one set of them is usually more regular and persistent than the other, making large smooth sides to the lump, while the other sides are more jagged and rough.

If the student will place a good sized clean lump of coal on the table before him, with the lamination horizontal or slightly inclined, he will have its whole structure clearly exhibited, and an excellent model before him for the exhibition of stratification and joints.

He will see that there is one set of smooth vertical surfaces along which there occur the cleanest, largest, and most even sides to the block, the vertical surfaces at right angles to that set being shorter, rougher, and more irregular. The first large smooth vertical surfaces are known by the name of "the face," "the slyne," or "the cleat" of the coal in different districts—the more interrupted set being spoken of sometimes as "the end" of the coal.

The "face" of the coal is the most necessary thing to attend to in laying out the working galleries or gate-roads of a coal-mine, since it retains its parallelism over very large * areas, and the main galleries must necessarily be driven along it, while the cross galleries run along the "end" of the coal. To attempt to cut galleries across that direction in which the coal will naturally split into blocks, would obviously be a much more difficult and expensive task than to take advantage of this structure.

* In inquiring of a collier in the Nottinghamshire coal-field, in the year 1838, as to the direction of "the slyne" (as the face is there called), I was informed that it "faced two o'clock sun, like as it does all over the world, as ever I heered on," by which I understood that the sun would shine directly upon it at two o'clock in the afternoon in an open work, or that the planes ran about W.N.W. and E.S.E., and were persistent in their direction in all my informant's district at all events.

Sometimes the "face" of the coal suddenly changes its direction, and I have been assured by Mr. Peace jun. of Wigan, that this is especially the case on opposite sides of a large fault. In some cases this occurs even in the same colliery, as at the Haigh Colliery, near Wigan, in which the face of the coal at one part runs in a direction 20° or 30° different from that in another, involving a similar obliquity in the "gate roads."*

Professor Phillips, in his Report on Cleavage, presented to the British Association for 1856 (p. 395), says that in the whole of the north of England coal-fields the strike of the cleat, or face, is about north-west and south-east, whatever may be the strike or dip of the beds.

I believe it to be a true "joint" structure, carried out more completely and minutely through the mass of the coal than through most other rocks, as we might expect in one of such a fine grain, light specific gravity, and homogeneous substance as coal, and one that has been subject to so much contraction as it passed from a mere mass of vegetable matter into the consistence of a rock. It is seen sometimes, however, in clay-slate, though not so minutely or perfectly carried out as in coal.

Art of Quarrying.—Just as this jointed structure in coal must be attended to in the process of cutting and extracting the coal, so the larger joints must be followed in quarrying stone. The shape of a quarry will depend altogether on the direction of the master joints which traverse the stone. One set of these joints will form what is called the "face" or "back" of the quarry, or the boundary wall towards which the men are at any time working, while the other set of joints at right angles to these are those along which they work, and these are called the "ends," or sometimes the "cutters" of the stone. The terms seem often to be used rather vaguely by quarrymen, just as they use the term "bed" or "floor" to signify sometimes a true bed surface, sometimes merely a surface formed by a horizontal joint. Whatever may be the terms used, however, it is clear that the whole art of quarrying consists in taking advantage of the natural division of rock by joints and planes of lamination and stratification, where the latter exist. There is no quarry, or road-cutting, or excavation whatever, in which these natural separations of the rock into blocks are not used either consciously or unconsciously.

Prismatic Joints.—The joints hitherto spoken of produce blocks which are more or less cuboidal in shape. In some rocks, however, the jointed structure has a tendency to produce long polygonal prisms, often resembling dry starch in their irregular and wrinkled sides. This prismatic jointing is most frequently exhibited in igneous rocks, such as the Doleritic lavas and the Traps, being especially characteristic of Basalt, but occurring sometimes almost as perfectly in

* In the Wigan district the "gate roads" are called "brows," and are spoken of as "upbrows" and "downbrows," according as they rise or decline from the "levels." The shorter passages which connect these "brows" are called "drifts."

Greenstone and Felstone. There is even sometimes an approximation to it in Granite, for the possibility of procuring long monoliths is the result of a more or less prismatic arrangement in the joints.

It is also observable in sandstones and clays that have been acted on by great heat, either naturally or artificially.

It may be seen on the small scale produced in the inside of ironstone balls and septarian concretions, and is occasionally, though rarely, observable in purely aqueous rocks.

I observed, in the year 1855, a very perfect example of this prismatic jointing in the gypsum quarries of Chaumont, near Montmartre, Paris.

Two beds, each six or eight feet thick, of crystalline granular gypsum, occur there, interstratified with the freshwater marls and limestones, and each of these was affected by a prismatic jointing, while in the soft beds in which they lay, few or no joints were observable.

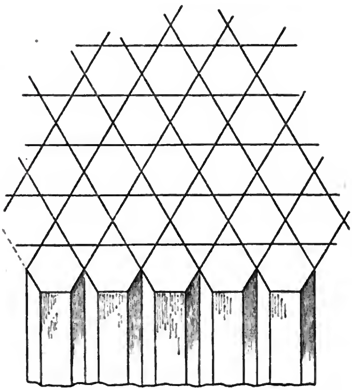


Fig. 23.
Joints in beds of granular gypsum (Chaumont, near Paris).

The prisms were pretty regularly triangular and hexagonal, as in Fig. 23.

The prisms seemed to have been produced by the intersection of three sets of vertical equidistant planes crossing each other at angles of 60°. If three such sets of planes intersect each other in the same points, triangular figures only could be produced; but if the planes be so arranged as that no more than two should ever intersect at the same point, and that each point of intersection be exactly equidistant from the planes of the third set, the result will be the production of a series of regular hexagons and triangles, as shewn in the figure.

Columnar basalt is a familiar example of this prismatic jointing. Basalt occurs sometimes in thick horizontal beds, the columns in that case being vertical, sometimes in highly inclined or vertical dykes, in which case the columns are nearly or quite horizontal. In each case the columns are at right angles to the surfaces of the mass, where the

cooling and consequent consolidation would necessarily commence, and appear to have struck thence into the interior.

It is often observable that in dykes the columns are separated in the middle, and do not fit each other, as if each set had originated at the side of the dyke, and struck towards the centre, where they met, but did not coalesce, as in fig. 24.

In some cases, the columns are more or less unbroken for many feet, a few cross joints only occurring at irregular intervals. This is especially the case in prismatic felstones.

Articulated Columns in Basalt, and other Igneous Rocks.—In other cases, however, especially in the most perfectly columnar basalts, the columns are articulated, each prism being separated into vertebræ, with a cup and ball socket occasionally developed on their upper or lower surfaces.

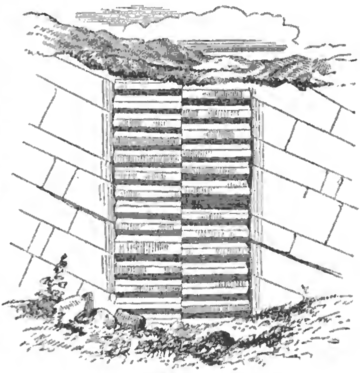


Fig. 24.
Dyke of columnar basalt, the columns not continuous across.

The origin of this articulated cup and ball structure is explained by the observations of Mr. Gregory Watt. If a mass of basalt be melted in a furnace, and allowed to cool again, the following results may be observed. If a small part be removed and allowed to cool quickly, a kind of slag-like glass is obtained, not differing in appearance from obsidian. If it cool in larger mass and more slowly, it returns to its original stony state. During this process small globules make their appearance, which, very small at first, increase by the successive formation of external concentric coats, like those of an onion, and the simultaneous obliteration of the previously formed internal coats, so that ultimately a number of solid balls are formed, each enveloped in several concentric coats. As these balls increase in size, their external coats at length touch, and then mutually compress each other. Now, in a layer of equal sized balls, each ball is touched by exactly six others (see fig. 25), and if these be then squeezed together by an equal force acting in every direction, every ball will be squeezed into a regular hexagon. But the same result will follow from an equal expansive force acting

from the centre of each ball, or from the tendency to indefinite enlargement in their concentric coats. Each spheroidal mass, therefore, will be converted into a short hexagonal pillar. But if there are many piles of balls one above another, each ball resting directly and centrically on the one below it, we should have a long column of these hexagonal joints, and the top and bottom of each joint either flat, concave, or convex, according to variations in the amount and direction of the pressure at the ends of the columns.

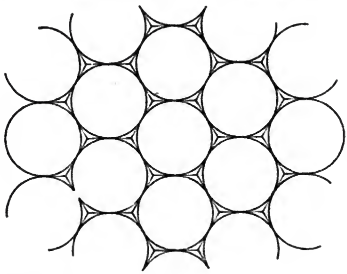


Fig. 25.

There is no apparent reason why, in a cooling mass of basalt, the balls should be so arranged as that their centres should be in straight lines, and that the hexagonal vertebræ should form straight continuous pillars rather than separate discontinuous pavements. This, however, is probably the result of the simultaneous tendency in the mass to split into prisms in consequence of the joint-forming action, the two tendencies acting together to produce the long columns with the short ball and socket articulations.

In the case of curved columns, it is probable that the accidental arrangement of the centres of the balls overpowered the tendency to produçe straight prismatic joints. Many other irregularities may frequently be observed resulting from the unequal action of one or the other tendency, and from the centres of the balls being irregularly distributed through the mass, since there are not only curved, but oblique and radiating columns, not only hexagonal, but pentagonal, triangular, and other irregular shapes, and in some instances small uncompressed or nearly uncompressed balls, may be found in the interstices between unequal and irregular columns.

The pillars of basalt are usually from 6 to 18 inches in diameter, and vary in length from 5 or 6 to 100 or 150 feet. Columnar greenstone is commonly on a larger scale, the pillars being sometimes 5 or 6 or even 8 feet in diameter, and the columnar form of the rock is often only to be perceived at a distance. Almost all greenstone exhibits the tendency to decompose into rounded spheroidal blocks, on which we have just seen the columnar structure partly to depend. Felstone is sometimes also beautifully columnar, of which an admirable example may be seen in a small pass to the southward of

Lough Gitane, near Killarney.—(See papers by Messrs. Du Noyer and Foot in the *Journal of the Geological Society of Dublin*, 1856, *and Explanation of sheet* 184 *of the maps of the Geological Survey, Ireland.*) Neither is this tendency confined to basalt, greenstone, and felstone, since it is sometimes perceptible even in granite, producing in that rock the "logging stones," or "rocking stones," the "cheese wrings," the "torrs," as well as the the "pots and pans," and "sacrificial basins," and other curious natural forms occurring in that rock, of which many have been attributed to ancient artificial processes.

Cause of Joint Structure.—In seeking for a cause for the production of joints in rocks, the first and most obvious one that occurs to us is, that they are the natural result of the contraction in the mass of the rock during its consolidation.

Mud or clay cracks in drying, molten rock cracks and shrinks in cooling. One of the chief difficulties experienced in large castings either of molten metal or in plaister casts is to guard against the formation of cracks, and this difficulty increases with the bulk of the material.

It has been several times attempted to turn to account the "slags" derived from iron furnaces by allowing them to run into moulds. An attempt was once made in South Staffordshire to run them into moulds of the size of large building-stones, and I have seen a large wall made of these molten blocks. The attempt, however, was abandoned, because after a short time the blocks crumbled into small cuboidal fragments, in consequence of the numerous minute concealed "joints" that traversed them.

In examining the newly formed beds of stone in the small islands upon coral reefs, I always found them divided by joints like other rocks. The consolidation of this stone was obviously due to the action of rain-water dissolving part of the carbonate of lime and redepositing it as a cement, so as to bind together the previously incoherent coral sand; for the stone generally rested on, and was surrounded by, coral sand still incoherent. Among the coral islands on the north-east coast of Australia I often observed several beds of stone resting on each other, each more than a foot thick, inclined at an angle of 8° or 10°; that is to say, at the same angle as the slope of the beach or bank of sand on which they rested. They had to all appearance been formed, that is consolidated, in this position. The joints which traversed them, although often uneven and jagged, ran in straight parallel lines over spaces sometimes of 200 yards, or as far as they could be seen, their planes being generally at right angles to those of the beds, one set of joints running along the greatest linear extension of the mass ("strike" joints), and the other set directly across the former, and in the same direction as the inclination of the mass ("dip" joints).

The directions of these two sets of joints seemed to depend in these cases on the *directions of the principal bounding surfaces or edges of the mass.*

I believe it is impossible that any kind of rock in large masses should pass from a fluid, or pasty, or soft condition into a hard, firm, and solid state without the production of a number of joints running in different directions through the mass.

It does not by any means follow that all the joints in any mass of rock should be formed at any one time. The consolidation of the mass may take place slowly and gradually, and successive sets of joints be produced in it at different times during that process. A rock moreover may be, at some subsequent period, placed under circumstances calculated to produce a greater degree of consolidation, and a fresh set of joints may be produced in it from that cause.

Neither does it follow that contraction on consolidation is the only agent that can produce joints, since they may possibly be formed in a mass of rock that is in a state of tension from a mechanically expanding force.

The small or short joints confined to individual beds of stratified rocks may have been those first formed on the original consolidation of the one bed before the other was deposited on it, those joints being then perhaps quite imperceptible divisional planes with no interspace between the blocks. Whole sets of beds may have subsequently been subject to one, two, or more actions of consolidation, which may have produced larger joints traversing the whole mass. Still more extensive joints may have been formed subsequently by the mechanical agency of the upheaving forces acting on the crust of the globe. Many more numerous joints may have split the rocks subsequently into smaller and smaller blocks in those parts where the rocks have been subjected to the expanding power of heat, and the consequent contraction on its withdrawal, as is sometimes to be seen in the aqueous rocks in contact with trap dykes or other igneous masses.

It would be no easy task now to assign to each particular cause the numerous joints which may be observed in all highly indurated and disturbed rocks. (See papers on jointing by Professor Harkness, *Journal Geol. Soc. Lond.*, vol. xv. p. 37, and by Rev. Professor Haughton, *Phil. Trans.*, vol. 148, part 2.)

Surface Exhibition of Joints.—In some places the jointed structure of rocks is sufficiently striking to attract the notice even of ungeological observers. In Van Diemen's Land, at a place called Eagle Hawk Neck, the rock, of which a large surface is exposed at low-water, is so regularly cut by joints into equal cubes, of about one foot in the side, that it has become a local celebrity, under the name of the "tesselated pavement."

The study of joints and the other divisional planes of rocks, and the

different forms assumed by them in consequence, both when freshly exposed and when modified by "weathering," is as necessary for the landscape painter who wishes to reproduce nature, as is the study of anatomy to the figure painter. Mr. Ruskin has handled this subject in his usual masterly style.

Natural Erosion of Rocks in consequence of Joints.—In the same way that the jointed structure of rocks facilitates their artificial extraction from their original site by the quarryman, it also facilitates their removal by natural causes. In examining cliffs, we may frequently be struck by the way in which a slight undermining action, if it happen to cut back to a strong vertical or highly inclined joint, has caused the ruin of vast masses of rock. Not unfrequently, too, a long strip of rock lying between two well-marked joints, closer than usual together, and running into the land at right angles to the coast, has been entirely cut out, giving access to the washing and eroding action of the breakers deep in among the rocks on each side of it.

The erosive powers of water in general, and especially of breakers, act not so much in proportion to the hardness or softness, or the greater or less durability of the material of which large masses of rock are composed, as to the number and position of the divisional planes of jointing and stratification which traverse them. A rock, even though very hard, such as quartz-rock or crystalline limestone, will be much more easily carried away by breakers or other moving water, if it be cut up by many open joints into blocks of a convenient size and shape, than much softer and more yielding rock, if it be massive, and either unjointed, or the joints be few and far between, and the sides of the blocks very close together, so as not to admit easily of the access of either air or water.

Instances of the action of the breakers on jointed rocks are to be seen on all coasts. The hard rocks of the western coast of Ireland afford many illustrative examples of the action as going on at present, their cliffs and rocky islets having been formed by this action. Mr. W. L. Willson, late of the Geological Survey of Ireland, once told me that in the far part of the promontory between Bantry and Dunmanus Bays, he met with dark holes in the fields some distance back from the edge of the cliffs, looking down into which the sea might be dimly seen washing backwards and forwards in the narrow cavern below.

In county Kerry, Ballybunion Head is completely undermined by caverns, into which the sea enters from both sides ; and in the county Clare, in the promontory north of the Shannon, which terminates in Loop Head, there are numerous instances of the sea penetrating, for some distance, beneath land one or two hundred feet in height, by working along certain joints in the hard grits and indurated shales, of which the land is composed.

At high-water, and during gales of wind, with heavy breakers rolling in upon the coast, vast volumes of water are poured suddenly into these narrow caverns, and rolling on, compress the air at their farther end into every joint and pore of the rock above, and then suddenly receding, suck both air and water back again, with such force as now and then to loosen some part of the roof. Working in this way, the sea sometimes gradually forms a passage for itself to the surface above, and if that be not too lofty, forms a " blow-hole " or " puffing-hole," through which spouts of foam and spray are occasionally ejected high into the air.

Mr. Marcus Keane shewed me, on a late visit to the promontory of Loop Head, considerable blocks of rock that had been blown into the air on the formation of one of these puffing-holes within his own recollection, and pointed out large holes opening down into cavernous gullies that lead from one cove to another, behind bold headlands of even a hundred or more feet in height, shewing the commencement of the process by which headlands were converted into islands. One such square precipitous island, which was now at least twenty yards from the mainland, was said by the farmer who held the ground to have been accessible by a twelve foot plank when he was a boy. Blocks of rock five feet across were pointed out that had, during recent storms, been rolled by the breakers, from among rocks twenty feet above high-water mark, up on to the grass full twenty feet higher and twenty yards further back.

The whole coast of Clare is a succession of precipitous cliffs with square faces, the result of the sea acting on the large cuboidal joints that traverse the rocks. The celebrated cliffs of Moher in that county, that rise with a perfectly vertical face to heights of more than 600 feet, afford magnificent examples of the joint structure, and of the way in which the ocean takes advantage of it to cut back into the land, however lofty or however hard and unyielding it may apparently be.—(See Mr. Foot's account of this coast in *Explanation of sheets* 141 *and* 142 *of the Geological Survey of Ireland.*)

CHAPTER XI.

MOVEMENTS OF DISTURBANCE IN THE EARTH'S CRUST.

In the two preceding chapters we have examined the facts connected with the deposition of rock under water, and those consequent on the consolidation of aqueous or igneous rocks. The problem that naturally presents itself next for solution is that of the elevation of rocks formed beneath the sea, and their appearance as dry land. Before attempting to describe the facts connected with this subject, however, it will be well, first of all, to glance over what is known respecting the general constitution of the earth.

Form of the Earth.—The earth is an oblate spheroid, the polar diameter being 7899.60 statute miles, and the equatorial, 7926.05,* or 26½ miles longer. The equatorial radius, therefore, is about 13¼ statute miles longer than the polar radius, or in round numbers 70,000 feet. If, therefore, we imagine a true sphere to be described within the earth, the radius of which shall be equal to the polar radius, the surface of that sphere will coincide with the actual surface of the earth only about the poles, but will sink beneath the actual surface, as we recede from the poles, gradually and regularly, till it is 70,000 feet deep under the equator (see fig. 26).

Let fig. 26 represent a section of the earth through the poles P P, and the centre *c*, the line P P being its polar diameter, and the line E E its equatorial diameter, and let it be drawn on a scale of 2600 miles to the inch. Then if an inner circle be drawn one-tenth of an inch inside P P, that will represent a depth of 260 miles, and the circle P *e* P *e* will represent the circumference of the supposed internal sphere drawn on the polar radius *c* P. The curved outer line P E P E will then represent the actual surface of the earth protuberant beyond this internal sphere, but this is not drawn to scale. The space between the letters *e* E on each side ought to be only $\frac{1}{20}$th of the space between P and the inner circle, whereas it is drawn nearly as ¼, since a twentieth of that space would not be visible to the naked eye. Making allowance for this necessary distortion the figure will represent the surface of the

* These numbers are those deduced by M. Bessel.—(*Mrs. Somerville's Physical Geography*, 4th edition, p. 5.)

earth bulging at the equator $13\frac{1}{4}$ miles beyond the supposed internal sphere, and a depth of 260 miles below that sphere.

This equatorial protuberance may, in fact, as Professor Henessey once remarked to me, be likened to a great mountain mass resting on

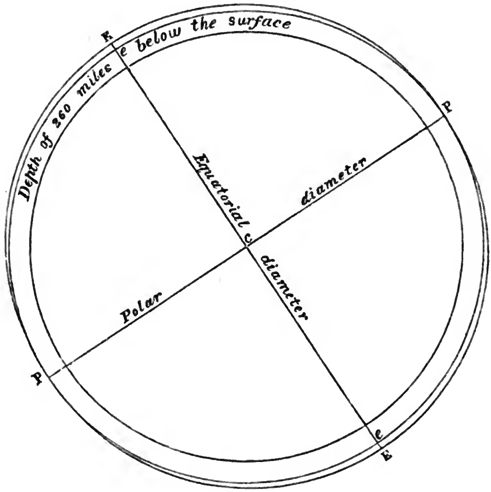


Fig. 26.

the supposed internal sphere, with a base equal to the whole surface of that sphere, and rising to a height of 70,000 feet above it under the equator.

The upper surface of the sea, or *sea-level*, will form the true mean or symmetrical surface of this protuberant shell. The dry land rises irregularly above that surface, and the surface of the bed of the sea sinks irregularly below it. The mass of the dry land, however, is so small compared with the bulk of this protuberant shell as to be quite insignificant, even when we take into account such a boss as the table-land of Thibet, with a mean height of 10,000 or 12,000 feet, and a diameter of 600 miles, or such occasional pinnacles as the Himmalayah Mountains, of which the loftiest, Mount Everest, rises 29,000 feet above the sea-level.

The depths of the ocean are doubtless greater than the heights of the land, but it may very well be doubted whether much of the surface of its bed, except in the Polar regions, sinks below the protuberant shell of the earth down to the surface of the supposed internal sphere before mentioned.

The irregularities in the surface of the earth are then merely *irregularities in its protuberant shell*, and they are largely compensated for by all their lower hollows being filled up with water, up to a height which must certainly be considerably above the mean level of these irregularities.

Stability of the Earth's axis.—This protuberant shell, consisting partly of earth and partly of water, provides for the stability of the earth's axis and the permanence of its form. The actual circumference of the earth's equator is about eighty-three miles greater than that of the circumference of the true sphere enclosed in it, and its movement of rotation is correspondingly more rapid than that of the surface of that sphere, inasmuch as each point of it is carried round that greater space in the same period of time. If, therefore, any disturbing action, either internal or external, tended to cause the earth to rotate on any other axis than the existing one, it would have to overcome the resistance of the greater centrifugal force now residing in the equatorial protuberance of the earth, and transfer it to some other circumference. It seems difficult to imagine any cause capable of this, but even if it existed, unless the earth immediately adjusted its form to its new motion, and transferred its protuberance to the new equator, the disturbance could only be temporary, and the earth would immediately begin to swing back, so as to rotate upon its shortest diameter as an axis, and its largest circumference as an equator.

It follows from this that ever since the earth assumed its present form of an oblate spheroid, the position of its axis must have almost certainly remained within it unchanged, and the points on its surface now occupied by the north and south poles must have always been its poles.

Whether the present axis of the earth always pointed to the same point of the heavens (making allowance of course for merely secular or periodical motions, such as that of nutation, or that on which the precession of the equinoxes depends), or whether it was always inclined $23\frac{1}{2}°$ * from the pole of its orbit, and the equator correspondingly inclined

* Astronomers inform us (see Herschel's Outlines of Astronomy, chap. xii., art. 680), that the obliquity of the ecliptic to the equator is now diminishing at the rate of 48″ in a century, but that after the diminution has reached a certain point, it will again increase, the amount of variation in their angle never exceeding 1° 21′.

If the ecliptic were actually to coincide with the equator, the result would be a great change in the climate of the earth, since there would be continual sunshine at the poles, and for a circle of 60 or 70 miles round them, no darkness greater than twilight in the major part of the arctic and antarctic circles, and equal day and night all over the rest of the globe. (Letters of Col. Sir H. James, R. E., Athenæum, September 1860.)

to the ecliptic is altogether another question, to which there seems to be nothing in the internal constitution or external form of the earth, calculated to give an answer.

Internal Temperature of the Earth.—It is, however, very remarkable, that the form of the earth as above described, is said to be almost exactly that of a sphæroid of rotation; that is the form which the earth would have assumed supposing it to have been once a fluid or pasty mass revolving with its present velocity. That the earth has this form, certainly raises a strong presumption in our minds that it was once fluid or pasty.

If so, is it more likely that that fluidity or semi-fluidity was a watery or an igneous one, in other words, were the materials of the earth in a state of solution, or a state of fusion?

The answer to this question must be sought in an inquiry into the condition of the interior of the earth at the present time. If the whole earth was ever in a state of fusion, are any traces or remains of that condition to be now discovered, in other words, what is the proper temperature of the interior of the globe? We may arrive at some conclusions on this point from the following considerations.

a. The phenomena of volcanoes pouring out molten rock on all sides of the globe, assure us that large parts of the interior, at least, are from some cause or other, so heated as to render the materials of solid rock perfectly fluid. Extinct volcanoes shew us that this was the case formerly with other parts of the globe, where the action is not now apparent.

Other masses of igneous rock, all connected with actual lavas by a regular chain of gradation, are found to have proceeded from the interior, up to, or towards the surface, even where there is no appearance now, and perhaps never was any, of actual volcanic cones upon the surface.

This almost universal appearance at the surface of once molten rock proceeding from the interior of the earth, convinces us that there must be some widely spread and general source of heat in that direction.

b. As a matter of direct observation, it is found that in all deep mines the temperature of the rock increases as we descend, at the rate of 1° of Fahrenheit for every 50 or 60 feet of descent after the first hundred. This is the case in every part of the globe, and in all kinds of rock. Numerous observations have been made with all possible precautions against mistake, and though the results vary in amount, they all agree in giving an increase of temperature. A recent case is mentioned in Mr. Hull's "Coalfields of Great Britain," where an abstract is given of Mr. Fairbairn's observations on the temperature of the deep coal pit lately sunk at Dukinfield, near Manchester. At a depth of

2151 feet, the temperature is constantly 75° Fahrenheit, while the constant temperature at a depth of 17 feet, was only 51° Fahrenheit. This gives an increase of 1° Fahrenheit for every 89 feet only, or less than the average.

Deep springs also, and wells, such as the deep Artesian well of Grenelle at Paris, are always found to have a high temperature. At Grenelle, the water brought from a depth of 1798 feet has a constant temperature of 81°.7 of Fahrenheit, while the mean temperature of the air in the cellar of the Paris Observatory is only 53°. Very accurate and careful observations have lately been made by M. Walferdin on the temperature of two borings at Creuzot, within a mile of each other, commencing at a height of 1030 feet above the sea, and going down to a depth, the one of 2678 feet, the other about 1900 feet. The results, after every possible precaution had been taken to ensure correctness, gave a rise of 1° Fahrenheit for every 55 feet, down to a depth of 1800 feet, beyond which the rise of temperature was more rapid, being 1° Fahrenheit for every 44 feet of descent.—(*Cosmos, May* 15, 1857.)

Hot springs are usually found to proceed from great faults or fissures which penetrate deeply into the crust of the globe.

c. Experiments formerly made on the attraction exercised by the mountains of Schehallion and Mt. Cenis, and lately on the deflection of the plumb line at Edinburgh, as calculated by the Ordnance Survey, under Col. Sir H. James (Phil. Trans., vol. 146, p. 591), as well as experiments with leaden balls, on the torsion balance, by Cavendish and Mitchell, and more lately by Mr. Baily (Somerville's Phys. Geog., p. 6, note), give a specific gravity for the whole earth, varying from 5 to 5.6. Recent experiments on the difference in the times of oscillation of a pendulum at the bottom and top of a deep coal mine at Harton, by the Astronomer-Royal, give as much as 6.56 for the mean density of the earth (Phil. Trans., vol. 146, p. 355.) We may confidently say, therefore, that the earth has a specific gravity of about 5 or 6. Now, the specific gravity of granite varies from 2.6 to 2.9; that of basalt is about 3.0; that of rock in general is from 2.5 to 3.0. The earth, therefore, is at least twice as heavy as it would be if made of any known rock, such as that rock appears at the surface.

The pressure of gravity, however, would render any such rock, as granite for instance, much more than twice as dense as it is at the surface, long before it reached the centre. According to Leslie, water would be as heavy as mercury at a depth of 362 miles, air as heavy as water at 34 miles. At the centre of the globe, steel would be compressed into one-fourth of the dimensions it has at the surface, and most stone into one-eighth, if the law of compression be supposed to be uniform from the surface to the centre.

We should therefore expect that the whole earth, if its substance be anything like homogeneous, and at all resembling granite for instance in constitution, would have a much greater specific gravity than 5 or 6, if it were not for some expansive force in its interior counteracting the pressure resulting from gravitation. We know of no such force except that of heat.* (See Lyell's Principles, chapters 32 and 33.)

It has consequently become the prevailing opinion of scientific men of late years, that the earth has an internal temperature of its own, altogether independent of any heat it may receive from the sun or other extraneous sources, and much greater than the temperature of the surrounding space, and that it consists of a cool envelope surrounding a highly heated interior.

Question as to Fluidity of central part of Globe.—If we could suppose that the rate of increase observed in mines and deep wells, that is to say, an increase of 1° F. for every 60 feet of descent or thereabouts, were to be continued indefinitely into the interior, it would follow that, at a depth of 10,000 feet beneath the British Islands, all water would be as hot as boiling water is at the surface, or 212° F. At a depth of about 20 miles, the temperature of all parts of the globe would be 1760° F.; and at 50 miles, would be 4600° F. Now, the heat of a common fire is calculated at 1140° F.; brass melts at 1860° F.; gold at 2016° F.; and platinum at 3080° F.

It would then appear that, if the increase of temperature be regular, all substances that we know at the surface must be molten at a comparatively slight depth; at about one-fifth of that, for instance, indicated by the inner circle in fig. 26. This fusion, however, does not follow as a necessary consequence, since we do not know how far the influence of increased pressure may operate to keep matter solid, even when raised to temperatures that would be more than sufficient to render them fluid if it were communicated to them at the surface of the earth.

Water at a height of 12,000 feet above the surface (as on the Peak of Teneriffe) cannot be made hotter than 190° F., since it boils, that is, it becomes steam, at that temperature. At the level of the sea it requires to be raised to 212° F. before it passes into steam; at the bottom of a deep mine the increased pressure of the atmosphere would keep it in the liquid state up to 214° F. or higher; and so we may well suppose, that at great depths water might be raised to 500° or 600° F., perhaps, and still remain water.

* This argument, if it stood alone, would not perhaps be of any great value, since it is open to anybody to deny the homogeneity of the interior of the earth, and to suppose that it is likely to contain a larger proportion of metal in the interior than near the surface, and that it may be a hollow sphæroid. The fact of a high internal temperature, however, may be held to be sufficiently proved by the two preceding arguments.

But what is true of a liquid passing into a vapour, is also true of a solid passing into a liquid state, although less is known of the relations between increase of temperature and of pressure in the latter case. It seems likely, however, not only that the melting points of solids should be largely affected by variations in the pressure to which they are subjected, but that different solid substances should be affected in a different ratio. If this be the case, it will follow that we cannot arrive at any definite conclusion as to the thickness of the solid crust of the globe from the consideration of the internal temperature only; and also it follows, that at some depth there must be a stratum of very high temperature, which is neither quite solid nor quite fluid, but passing from one into the other as the increase of temperature gradually overcomes the effect of pressure.

Should this be the true condition of the interior of the earth, it may well be that the earth may have a comparatively thin crust over a completely fluid centre, and yet that there shall be such a gradation from one into the other, that the fluid nucleus shall not move freely within the solid crust, but the whole rotate together as one body, and hence, that the fluidity of its interior shall have no effect on the rotation of the earth, and not be discoverable by any astronomical investigation.

The student will find a more complete discussion of this subject in various papers by Mr. W. Hopkins of Cambridge, and Professors Haughton and Henessey in the Philosophical Transactions, and the Transactions of the Royal Irish Academy.

Exciting causes of disturbing action on Earth's Crust.—If the idea of an intensely heated, more or less fluid, centre, with a comparatively thin cool crust, be a true conception of the condition of our globe, it is obvious that we have an abundant source of igneous action and of mechanical movement in different parts of that crust from time to time, provided we can admit of local exciting causes producing an occasional determination of the internal heat towards certain spots or lines of the surface.

What is the exact nature of these local exciting causes is a question to which no perfectly satisfactory answer has yet been given. One of them may perhaps be, as supposed by Bischof, the access of water through cracks and fissures to a deep and intensely heated level, and the consequent generation of highly explosive steam; but then this leaves unaccounted for the previous production of these very cracks and fissures.

The hypothesis of the oxidisation of the metallic bases of the earths and alkalies producing a local intensity of heat, seems likewise to involve the access of air and water to spots they had not before reached, and to require the providing of the means of access for them.

For the present, however, we may dismiss speculation as to the precise cause or mode of action of the elevatory and disturbing force, and turn our attention to an examination of its results.

To produce a permanent change of relative Level between the Surface of Land and Sea, the solid part of the Earth's Crust must move first.— It is clear that all rocks which were formed at the bottom of the sea, and which are now dry land, must have gained their present situation either by the sinking of the sea level, or by the uplifting of the sea bottom. If, however, the level of the sea be materially lowered in any one part of the globe, it must be equally lowered over its whole surface. But we find aqueous rocks on the summits of some of our highest mountains, and if these had been laid dry solely by the sinking of the sea, without any movement of any kind in the solid crust of the globe, we must suppose that a shell of water as deep as our highest mountains has been removed bodily from the earth into another part of the universe.

For if the quantity of water in the ocean remained the same, its surface level could not permanently sink, unless there were a hollow made in the solid part of its bed for the water to sink into. Neither could its surface level be permanently raised, except by the filling up of some of the deeper parts of its bed by the deposition of earthy matter ; or else of a contraction of the capacity of its bed by the rising of the solid rock below it. If the quantity of water on the globe, then, remain the same, any permanent change in the level of the sea, even if it were an equal and uniform change all over the globe, could only be caused by a previous change of position in some of the solid parts of the crust of the globe.

But if this be true for even a general change of level common to the whole globe, still more obviously true is it for a local and partial change in the relative levels of land and water at any particular spot of the globe, or in any limited area, such as the Baltic Sea, for instance.

Wherever, then, we find that a change has occurred in the relative levels of land and sea in any portion of the globe, we must believe that the elevation or depression has originated *in the solid rock*, and not in the fluid ocean. The very fluidity, indeed, of the ocean, which might at first lead us to look to its motion and change of place as the cause of the appearance of dry land, renders any permanent *local* change in its level impossible, while a local change in the level of solid rock is more easily possible than a general or universal one.

Motion in Rocks proved by inclination of Beds.—We may arrive at this conclusion in another way. We could not continue our observations upon stratified or aqueous rocks very long without perceiving that their beds are not invariably horizontal, but are, on the contrary, generally inclined to the horizon. Now, we have already seen that in certain cases beds of stratified rock may be formed on a considerable

slope, or may have an original inclination due to the very circumstances of their deposition. These cases, however, are, by their very nature, limited to small areas. A steep slope cannot be of indefinite extent in every direction, and could not have strictly parallel beds deposited on it over its whole area if it were. Whenever, then, we have very widely spread beds, maintaining an equal thickness and strict or approximate parallelism over a large extent of ground, we may feel perfectly sure that those beds when first formed were practically horizontal. If such beds are now found in an inclined position, we may be equally certain that they have been moved since their formation, and moved more in one direction than in another. They must have been *tilted*, either by being lifted up at one end or depressed at the other. In many cases we find this motion to have been very great; the beds have been tilted and set on edge so as to rest at very great angles, and in some cases to be absolutely vertical. Beds consisting of alternations of clay and sand, with thin seams of round pebbles that must clearly have been deposited horizontally, have been tilted up till they are now perpendicular (see fig. 27). No one could look at a cliff exhibiting these facts, without feeling certain that in this case, at all events, some subterranean and internal forces had acted upon previously horizontal beds, and lifted them into their present position.

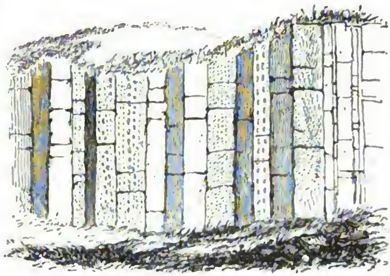


Fig. 27.

Beds containing layers of round pebbles, which must, therefore, have been deposited horizontally, now in a vertical position.

Motions in Earth's Crust during recent times.—If we still hesitated to believe motion in the solid frame-work of the earth possible, our scepticism must at length give way before the knowledge of the fact that it is still going on, even in our own day, in various parts of the earth. For a compendious account of movements of elevation and depression in the lands of the present day, either having occurred within the times of history or still in progress, I must refer the reader to Sir C. Lyell's Principles of Geology, chapters xxix., xxx., and xxxi. He will there find an account of the gradual rise of Sweden and Norway, which is now going on at the rate of about three feet in a century; of

the frequent elevation of land along the west coast of South America, simultaneously with the occurrence of earthquakes; of the depression of the west coast of Greenland; and of both the elevation and depression of the temple of Jupiter Serapis, and its neighbourhood, in the bay of Naples, and other similar facts in other parts of the globe.

More recent movements still were mentioned by Sir C. Lyell, in a lecture to the Royal Institution in 1856, as having occurred in New Zealand simultaneously with the earthquake of January 1855. A *step* of rock, bared of earth, nine feet high, was traceable for ninety miles at the edge of a plain along the foot of a range of hills. An elevation of five feet took place on the north side of Cook's Straits, so as almost to exclude the tide from the river Hutt, and a corresponding depression on the other side of the straits allowed the tide to flow up the river Wairua several miles higher than before.

That these permanent changes of level have not been more often observed is probably in great part owing to the want of a natural standard of level. A change of level diffused over a considerable area could only be detected on the sea coast, or by accurate measurement referring to some standard of level which had not itself been disturbed. Our only natural standard of level is that of the upper surface of the sea.

The movement of the land in Scandinavia and Greenland is so slow and gradual as to be quite insensible, the inhabitants only becoming aware of it by its results, and naturally referring it to a movement in the sea rather than in the land.

More frequently, however, movement in the crust of the earth appears to be accompanied by earthquakes, which are probably the results of a sudden yielding or fracture in the solid frame-work communicating a jarring vibration and undulation to the parts above and around it. Every earthquake is probably accompanied by a dislocation in the rocks shaken. That dislocation sometimes perhaps extends to the surface, but it is clear that the bending and fracture of the rocks will be greatest nearest to the origin of the disturbing force, the amount of disturbance being gradually relieved as it travels towards the surface.

The frequency of earthquakes, if we take the whole earth into account, is much greater than would be supposed by the inhabitants of any one country, more especially if that be one of the regions not now affected by earthquakes. In the earthquake catalogue of the British Association, compiled and discussed in so admirable a manner by Mr. Mallett and his son, he mentions, for the three last years of his catalogue, 86 earthquakes in 1840, 152 in 1841, and 92 in 1842, so that two or three earthquakes occur every week, even of sufficient magnitude to be recorded, to say nothing of others that are not recorded, either from their minor character or from their occurring in parts of the earth not inhabited by civilized man.

The frequency of earthquakes, and especially their frequency in particular districts, and the undulatory motion by which they are often accompanied, which has been described as producing a sickening feeling, as if the land were but thin ice over heaving water, proves to us the instability of the earth's crust.

The fact that all our present lands were formed beneath the sea is, if we admit that the sea-level is practically invariable, perfect demonstration of elevation having taken place. It is not so easy to prove the fact of depression, since the very act of the sinking of land below water takes it out of the reach of our observation.

Depression proved by Coral Reefs.—The great coral reef Atolls and Barriers, however, here come to our aid, since Darwin has long ago shewn that their form and bulk are only explicable on the supposition of a slow and gradual depression of the ocean bed from which they rise.

The species of coral which produce great reefs can only live in shallow water, where the heat and light are both vivid, and where the motion and play of the waves are rapid and continuous. Great wall-sided Atolls and Barriers, then, rising from depths of 2000 feet, must have commenced their growth in shallow water, and continued it upwards, at such a rate as to have always kept their living surface near to the surface of the ocean, while the rock base on which they rested gradually subsided beneath it.

Fringing reefs are those growing along the margin of a rocky shore. If the land, which has always a general inclination from the interior towards the shore, should be depressed, the sea will flow farther in over it than before, and the new shore will be further and further from the outer edge of the reef as the depression is continued. But the outer edge of the reef will nearly maintain its place, because it grows vertically, or nearly vertically, upwards, so that eventually there will be a channel of water between the outer edge of the reef and the land, which channel will be wider in proportion as the slope of the old land was gradual.

In this way a Fringing reef becomes converted into a Barrier reef.

If the Barrier reef entirely surround an island, and the depression be continued until the whole of that island sink beneath the sea, the Barrier reef will then no longer have any land to circle round, and will pass into an Atoll or ring of coral reef, with or without islets of coral sand heaped upon the coral rock, which gradually become clothed with vegetation, and ultimately, perhaps, the home of man.

The great Barrier reef running along the north-east coast of Australia resembles in outline a line of soundings such as are often marked in charts, receding from the present shore, where that is low, or where the slope of the subjacent rock is gradual, and approaching to it where the land is lofty and steep, and the submarine slope therefore rapid.

It marks then, with very approximate accuracy, the limits of the land of Australia as it existed when the corals first settled on its shore as a Fringing reef, and proves to us the fact that that old land was once higher above the water, and its coast, therefore, farther out to sea than at present.

Two Modes of Action in Forces of Disturbance.—The internal force which produces this elevation and depression of the surface of the earth acts apparently in two ways, broadly and equably, or with local intensity.

When it acts broadly and equably, the motion seems to be insensible and unaccompanied by earthquakes, and great tracts seem to be lifted or depressed bodily, without any change in the external surface, and without any disturbance, so far as we can see, in the interior.

When it acts with local intensity, either along lines or upon points, it is probably always accompanied by earthquakes, and produces disturbance and dislocation in the parts acted on, causing the contortions and faults that will be presently treated of, and tilts the beds into those highly inclined positions which we see about mountain chains.

We shall see reason to believe that these great disturbances are always produced at some depth in the earth's crust, and that their most marked effects only appear at the surface when they are exposed by denudation after being brought up by a subsequent broad and equable elevation.

It is, however, quite possible that the two kinds of motion are often conjoined, and that the convulsive action on deeply subterranean lines or points may be combined with widely-spread elevation or depression.

CHAPTER XII.

INCLINATION OF BEDS.

The Dip and Strike of Beds.—The inclination of beds downwards into the earth is technically called their "dip." It is measured by the angle between the plane of the beds and the plane of the horizon. In fig. 28 the beds dip to the south at an angle increasing from 35° to 50°. When we speak of the opposite of "dip," we use the term "rise." For instance, in fig. 28 the beds *dip* to the south, and *rise* to the north. The place where each bed rises out to the surface of the ground is called its "outcrop" or "basset." We say that such and such beds "crop out" to the surface, and we speak of the "basset" edges of the beds. Miners use these and other terms, such as "coming out to the day," "rising up to the grass," when speaking of the "outcrop" of any bed or beds. The line at right angles to the dip, that is, the line of outcrop of a bed along a level surface, is called its "strike," a term introduced from the German by Professor Sedgwick. It is described by its line of compass bearing, either true or magnetic.* Coal miners commonly speak of this as the "level bearing" of a bed, seeing that if you draw a line or drive a gallery along a bed exactly at right angles to its line of dip or inclination, it must of necessity be on a true level or have no inclination either way. It must be recollected that the true strike of a bed will coincide with its line of outcrop along the surface of the ground only when that surface is horizontal. If the surface be highly inclined, the outcrop of the bed along that surface will depart from the true strike in proportion to the inclination of the surface, until it coincide with the dip when the surface becomes perpendicular.

If, then, a bed "dips" due north or due south, its "strike" will be due east and west. If we know the direction of the "dip" of a bed, accordingly, we also know the exact bearing of its "strike;" but if we only know the strike, we do not necessarily learn either the direction or amount of its "dip," because it may incline to either side of the line of strike, and to any amount from the horizontal plane. In making observations, then, in field geology, it is most important to observe

* Geologists generally use true compass bearings, a practice that ought to be adopted universally in all land operations.

accurately the direction of the dip of all stratified rocks. It is also important to know its amount; but this need not be observed with such minute accuracy, since it is apt to vary continually to the amount of 3° or 4°.

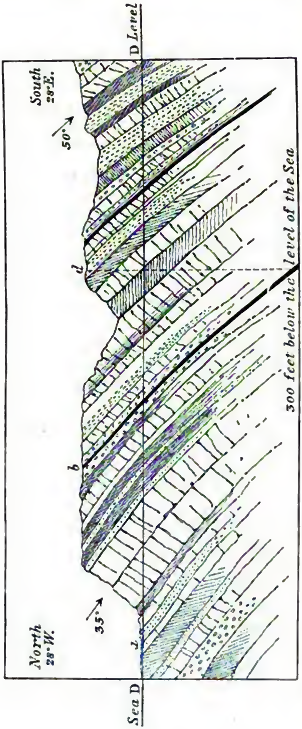


Fig. 28.
Vertical section along the line DD in the map Fig. 29.

Geological Section and Map.—In order to make the explanation more clear, let figs. 29 and 28 be a rough map, and a section across it, of a supposed piece of ground near the shore, and let them both be drawn on a scale of about 100 yards (or 300 feet) to the inch. In the map, fig. 29, let A A be a rocky beach, exposed at low water; B B a line of cliff about 100 feet in height; and C C the surface of a country above the cliff, with the rock exposed in several places, either on the summits of eminences or the bottoms of quarries. The arrows will point out the direction of the dip, the figures shewing its amount. This amount increases from 35° on the north to 50° on the south, and we may assume this increase to be quite gradual, or that the beds are parts of curves, and not of perfectly straight planes. Then let D D be a line of section, or supposed cutting, at right angles to the strike of the beds, and let this section (fig. 28) be drawn so as to give the true outline of the ground across which it passes, and represent the beds in the true position they would be seen to occupy were such a cutting or cliff really formed. Being drawn at right angles to the strike, it runs of course along the line of the direction of the dip and its bearing, as here drawn, is about 28° west of north, and east of south. The latter, then, is the

direction of the dip.. The bearing of the strike will consequently be 28° north of east if we look in one direction, 28° south of west if we

Fig. 29.

look in the other. In such a locality as this, if we marked out the boundaries of the beds correctly on our map, we should feel sure of the

correctness not only of the map, but of the section, and we should know the position of the beds not only above the level of the sea, but for a considerable distance below it. If, for instance, at the point *d* in the map we wished to determine the vertical depth of the bed *b*, we should see at once, by constructing the section, that the depth of *b* under *d* would be, according to the scale, rather more than 425 feet. If we wished to reach the bed *a* in the same way, it would be easy, either by construction or calculation, to ascertain the depth at which it would be found in a perpendicular shaft under *d*.

It would be easy for us also to ascertain the total actual thickness of the whole set of beds shewn on the map, either by actual measurement of each bed along the shore, or by constructing a section founded on the observation of their angle of dip and the width of their outcrop. The actual thickness of the beds cut by the sea-level line in the section fig. 28, for instance, would be a little over 850 feet. That is to say, those beds, if they were horizontal, would be 850 feet from top to bottom; if they were vertical, it would be 850 feet directly across them; while in their present inclined position, a horizontal line across their outcrop measures 1200 feet. In the Appendix will be found a table which will give either the depth of any particular bed, or the thickness of a group of beds when the angle of their dip and the width of their outcrop is known.

If we proceeded to trace those beds into the country *along their strike*, however much the direction of the strike or the *angle* of the *dip* might vary, or however they might be concealed by grass, soil, or superficial covering, we should always have to recollect that there was a thickness of 850 feet of beds to be found or allowed for somewhere; and if we came to a quarry or a cutting where the bed *x*, for instance, was shewn, and we were able certainly to identify it, we should expect there to find all the other beds above and below it that we had found above and below it where they were clearly exhibited. We should feel sure we were right in this, if in the expected spots, at the requisite distance on either side of it, we found one or more of the beds *a*, *b*, or *c*, shewn in other quarries, or cuttings, or cliffs in the neighbourhood.* It is in this way, by getting a knowledge of the true section of a series or group of beds where they are well exhibited, and following them across a country, picking out one of them here, and another of them there, in ditches, brooks, river banks, cliffs or ravines, wells, mines, road or railway cuttings, and quarries, that geological maps are constructed, shewing the boundaries of the several groups of rock, their

* In diagram fig. 29, the supposed quarries or exposures of rock in the interior of the country are thickly grouped together; but if the reader will imagine them separated by much wider intervals, and scattered over a far larger space, he will have a truer notion of what usually occurs in nature.

range or strike across a country, and the area of surface they occupy with their outcrops or "basset edges."

Contortions.—Where the dip and strike of the rocks are very steady, or where they run in nearly straight lines across a country, and their edges are not too much concealed by superficial covering, the task first mentioned is one of no great difficulty. In many instances, however, neither the dip nor the strike of a set of beds remains constant over any considerable spaces. The beds are bent and contorted, and twisted about, so that, instead of running in straight lines, the basset edges, or outcrops of any set of beds, follow crooked and curved lines, often doubling back and running altogether out of their former course. Moreover, after dipping down in a certain direction for some distance, such beds are frequently curved up again, and rise to the surface at some other locality, forming basin or trough-shaped hollows; or again, after cropping out to the surface, the beds underneath them are bent over in a ridge-like form, so that the first beds come in and take the ground again, dipping in an opposite direction.

These bendings of the beds occur on every possible scale, from mere little local crumplings on the side of a bank, to curves of which the radii are miles, and the nuclei are mountain chains. When on the small scale, they are commonly called "contortions," as in fig. 30.

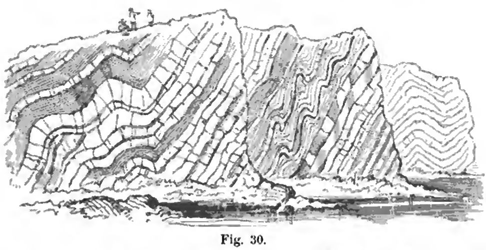


Fig. 30.
Sketch of a cliff on the coast of Cork, near the old Head of Kinsale, by Mr. G. V. Du Noyer.

Beds of the hardest stone, such as compact or crystalline limestone, and hard siliceous gritstone are in some cases bent into curves of the most wonderful regularity, so as to look like artificial masonry, or a series of arches and troughs built for some inexplicable purpose.

More usually, however, there is a good deal of irregularity in the curves, and this is especially the case when the beds acted on consist of alternations of different texture and composition.

The sketch, fig. 31, represents part of a series of contortions in the Carboniferous limestone of the County Dublin, as they may be seen on

the shore of Loughshinny, between Rush and Skerries. In this locality they may be studied not only in section in the cliffs, but in

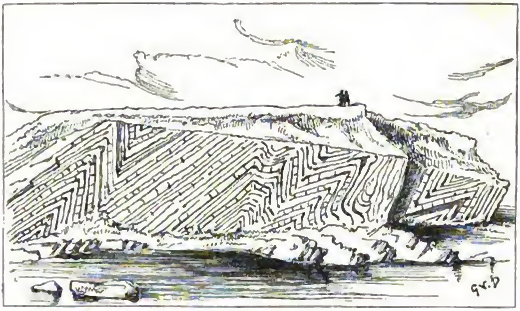


Fig. 31.
Sketch of contortions in carboniferous limestone and shales, Loughshinny, County Dublin.

plan on the shore at low water, and some of them may be observed partly in section and partly in plan, which makes the locality an exceedingly interesting one.

The ridges and troughs form long ovals, the ridges, like inverted boats half shewn through a succession of planks wrapping round them, the troughs like a series of broken boats of less and less size, placed inside each other like a nest of boxes. These oval ridges and troughs succeed and replace each other in all directions, and where the one passes into the other, the crumpling has been sometimes so great, and the squeezing so severe, that it is impossible to trace any bed, or even any two or three beds through the contortion.

It will be seen that in some parts of the sketch the dark shale beds are wider than at others, the soft shales having been squeezed out from between the limestones at one place, so as to form "pockets" at another. This sometimes happens on a still larger scale, with violently contorted beds. In the collieries near Kanturk, County Cork, the culm and anthracite beds there, which were originally perhaps 2 or 3 feet thick, expand in some places to a width of 20 or 30 feet, while at others they dwindle down to a single inch. The same thing seems to occur with the seam of anthracite, in the Lower Silurian beds near Upper Church, County Tipperary, and at Kilnaleck in the County of Cavan. (See Explanation of sheets 145, 163, and 175, Geol. Surv., Ireland, description by Messrs. G. H. Kinahan and A. B. Wynne.

Similar instances may sometimes be seen among disturbed rocks of the sudden thickening and thinning of argillaceous beds, due not so much to irregularities of deposition as to subsequent squeezing.

Very curious and almost inexplicable contortions may be seen occasionally, but we must recollect that the conditions under which they were produced were such as it is not often possible for us to imitate, nor easy even to imagine. When the rocks were thus contorted, they were buried under vast thicknesses, often many thousands of feet, of other rock; the rocks above and below them were also of unequal densities, and offering unequal resistances to force; the forces of disturbance, therefore, even if uniform in their origin, would become complicated in direction, and unequal in intensity, by reason of these inequalities in the structure and position of the rocks, and inequalities in the pressure of the superincumbent masses.

Repetitions of disturbing action.—Another source of confusion is the repetition of a disturbing action upon rocks already disturbed, the subsequent forces acting perhaps in directions different from the early ones. In Ireland it can be shewn that the Cambrian rocks were greatly disturbed and contorted before the deposition of the Lower Silurian, that the Lower Silurian formation had in like manner suffered before the deposition of the Carboniferous, and that the Carboniferous had itself been greatly disturbed and often highly contorted. It is reasonable therefore to expect, what is found to be the fact, that the beds of the Cambrian rocks are in some places twisted into a confusion of curves and knots, which it is now a quite hopeless task to endeavour to unravel.

Anticlinal and Synclinal Curves.—When the curves of the rocks are of greater extent, we cease to speak of them as mere "contortions." If the curves have longly-extended axes, that is to say, if the beds are bent up into ridges, or down into troughs, which continue for considerable lengths, in proportion to their widths, we speak of them as "anticlinal" and "synclinal" curves. If, on the contrary, no diameter of the curved area be much longer than another, we call them either dome-shaped elevations, or basin-shaped depressions, as the case may be.

In fig. 32, A is an anticlinal, and B is a synclinal curve, the beds numbered 6, 7, 8, being repeated on each side of both. At A, the lower beds, 1, 2, 3, 4, 5, are seen rising out from underneath them in the form of an arch. At B, the upper beds, 9 to 13, repose upon them in the form of a trough. It matters not whether we suppose the spaces, 1, 2, 3, etc., to represent single beds, and the hill at A a slight elevation, or whether they be taken as groups of beds, and A be supposed to be a mountain chain.

The straight line which may be supposed to run directly from the

eye of the spectator along the top of the ridge A, or the bottom of the trough B, is called the "axis" of the curve in each case. This axis may be either horizontal or inclined; if horizontal, the section across it

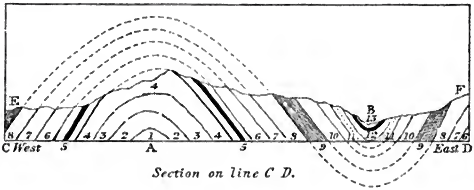


Fig. 32.

will cut the same beds wherever it be taken, the variations in its outline only resulting from those in the outline of the ground. If, however, the axis be inclined, different sections will cut different beds, even should the outline of the ground remain the same. This is shewn at fig. 33, which is a supposed plan of the ground of which fig. 32 is a

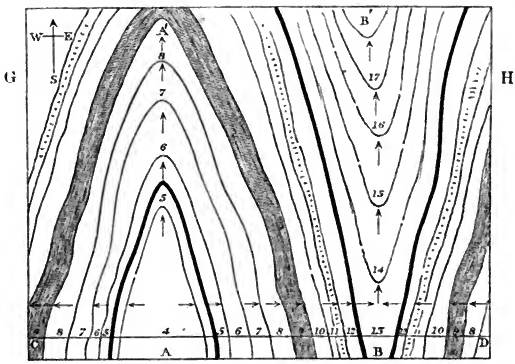


Fig. 33.
Plan of Undulating Beds.

section, in which the axes, A A^1 and B B^1, are supposed to incline downwards to the north, or from the line of section C D, to the other end of the map, as shewn by the arrows, it is obvious that the bed 4, which forms the apex of the ridge in the section, will slope downwards

along the inclined axis, and if the ridge of the hill be kept up to the same height, the beds 5, 6, 7, 8, will necessarily arch over it. In the same way, if the synclinal axis B B¹ slope in the same direction, there must either be a corresponding slope and hollow in the surface of the ground, or fresh beds, 14, 15, 16, etc., must come in, resting in the hollow of 13. So that, if we make another section, as in fig. 34, along

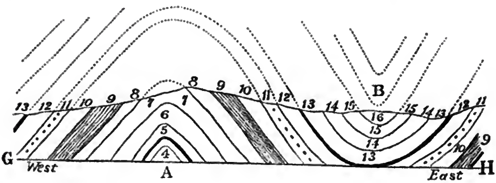


Fig. 34.
Section along a line between G and H.

a line between G H for instance in fig. 33, the ridge of the anticlinal A A¹ will be formed by the bed 7 instead of 4, all the beds below 7 having successively sunk beneath the surface, and the bed 16 will form the hollow of the synclinal B B¹, the bed 13 being now at a considerable depth below it, and cropping out at some distance on either side.

Large anticlinal and synclinal curves have often minor undulations

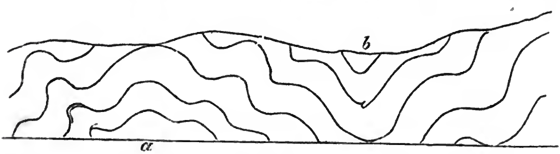


Fig. 35.
Sketch section, to shew major and minor folds in rocks.

on their flanks, as suggested in fig. 35, where the letters *a* and *b* shew the main anticlinal and synclinal, with smaller ones on each side.

These minor undulations may be likened to ripples or lesser waves riding on the back of the larger swell of the ocean. They are especially remarkable in some of the large anticlinals in the south-west of Ireland.

It will be readily understood that such complication of forms as these necessitate great labour in making an accurate map of the country, more especially where the ground is itself lofty and broken, and

often difficult to traverse, while the subterranean complication is only partially revealed by occasional exposures here and there at the surface.

The axes, or imaginary central lines of anticlinal and synclinal curves, are sometimes long and steady, and the curves themselves apparently endless in length, sometimes the axes are short and interrupted when the anticlinals and synclinals shrink into short oval ridges and troughs, like those mentioned at p. 238, and these again pass into strictly dome-shaped elevations and basin-shaped depressions, when the axes become mere points or centres, from or towards which the beds have what is called a *quâ quâ versal* dip or inclination on all sides. When the axes of the curves are short and interrupted, the curves themselves are, as might be expected, irregular, so that an anticlinal presses into a synclinal along the same line of strike, and *vice versâ.*

The axis of an anticlinal or synclinal curve may run either in the direction of the general dip of the beds, or, as is most usual, in that of the strike, or intermediate between the two, producing one or two local flexures in the beds, independently of their general inclination.

Uniclinal Curves.—This term, first used, so far as I am aware, by Mr. Darwin, in his Geology of South America, may be useful sometimes to designate a single fold in rocks, without any answering counterfold in any direction. If, for instance, a set of horizontal beds suddenly curve down or up into a vertical or nearly vertical position, and either continue highly inclined or merely pass back again into their original horizontality, without rising or falling by a corresponding curve, we may call it a uniclinal curve.

In the Isle of Wight, for instance, the beds are horizontal at the southern end of the island, suddenly dip in the middle of it vertically or nearly so, to the north, and then rather quickly recover their horizontality at the northern end of the island. This uniclinal curve causes the beds which cap the hills in the south to be deep below those forming the low ground in the north of the island.

Some magnificent examples of uniclinal curves may be seen along the cliffs near Loop Head, County Clare. The beds there are hard grits and indurated slaty shales belonging to the Coal-measures. In many places they are horizontal, or nearly so, while in others they are variously curved, the anticlinals sometimes eroded by the sea below so as to form natural arches and bridges, one example of which is well known as the Bridges of Ross. In two or three instances, however, horizontal beds are suddenly bent for a short space by uniclinal curves into the vertical position, and then immediately bent back again into the horizontal. The axes of these curves strike nearly with the coast, so that great areas of the surface of a bed are sometimes shewn in the cliffs. One of these is one or two hundred yards long and two hundred feet in height,

and Mr. Henry Keane, on whose property it is, has had one of the projecting crags near it walled round, so that it may be viewed in safety. As the smooth nearly vertical surface of the bed undulates slightly, it might be taken for the side of some mighty ship rising out of the boiling surf below.

Inversion of beds.—These flexures are in some instances carried out so far, both on the large and small scale, as to produce actual inversion (see fig. 36) of the beds, so that the lower surfaces appear in some places to be the upper ones.

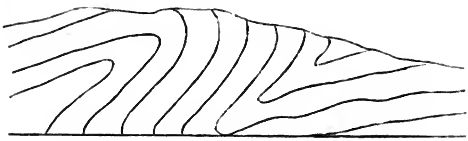


Fig. 36.
Section shewing inversion.

This inversion may, in some cases, among highly contorted beds, be actually seen in the cliffs, as in some parts of the Alps, where the beds may be observed bent into the form of S's or Z's, in the precipitous sides of the mountains. In other cases it requires a more widely extended observation, in order to shew that the apparent order of superposition of any set of beds, in any particular locality, is the inverse of that order which is to be observed generally, and where the beds are undisturbed.

Inversion of beds is occasionally to be detected by means of the "ripple," or "current mark," or other structure produced on the surface of beds, when the peculiarities in the forms of these marks are of such a kind as that a "cast" of them shall be plainly distinguishable from the original form. In these cases the "cast" may sometimes be seen on the now upper surface of a bed, dipping under what appears to be the bottom of the superincumbent bed, but which was originally the really upper surface or "mould" on which the materials were deposited that formed the "cast" at the bottom of the succeeding bed.

The inversion of beds is occasionally observed in coal mining, as in Belgium and the south-west of Ireland, where beds of coal are sometimes found with the "coal-seat" uppermost, and the "coal roof" undermost. In a disturbed part of the South Staffordshire coal-field, the same bed of coal was passed through three times in the same vertical shaft, first in its right position, then inverted, and then again right side uppermost. It must accordingly have been bent into the shape of the letter S or Z.

We shall see presently that no mere "fault" can thus bring part of the same bed twice into a vertical shaft.

Artesian Wells.—The artificial wells known as Artesian, from their first being used in the province of Artois, are possible only in those districts where the rocks have been bent into a basin-shaped curve. If a series of beds, some of which are porous, either in consequence of their open grain, or the joints which traverse them, while others are impervious to water, be bent into the form of a basin with a quaquaversal dip towards a central part, and the porous beds rise into higher ground than that central part, then the rain that falls on their outcrop will partly sink down along them beneath the impervious covering until a basin-shaped sheet of water be accumulated below, as in the shaded part of fig. 37. This water will completely saturate the porous bed up to a certain level, as L L for instance, but will be prevented from rising to the surface in consequence of the impervious bed or beds *m m* above it.

If that impervious downward-curved bed be pierced by a bore-hole, the water will rise in that hole to the level L L, and this is in some cases above the level of the surface of the ground in the low central region, as represented in fig. 37.

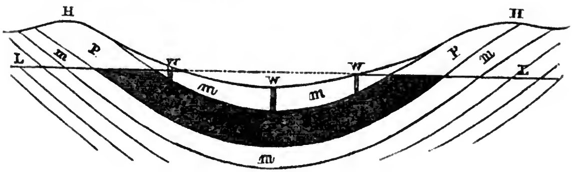


Fig. 37.
Diagrammatic section of a district in which Artesian wells are possible.

In this diagram the porous beds are indicated by the letters PP, and the impervious beds by the letters *m m*. If then the wells W W W be sunk through the upper impervious beds, the water will rise in them, either on to the surface with a jet as in the central well, up to the surface as in the one on the right hand, or up to the water-level LL in the one on the left hand, that water-level being the height to which the beds P P are supposed to be saturated with water from the rain falling on the high ground H H.

If the water-bearing beds be traversed by many open joints, the water will flow freely through them, and rush up the moment it is tapped. If, however, the joints be few or close, and the rocks be close-grained, it will then require some time for the water to rise in the wells.

CHAPTER XIII.

FAULTS OR DISLOCATIONS.

It may easily be conceived, that the force which was sufficient to raise vast masses of solid rock, of unknown but immense thickness, from beneath the bottom of the sea high into the air in order to form the dry land, and to bend them into the folds and contortions that have been just described, was also sufficient to crack and break them through. We find, accordingly, very frequent instances of cracks and fissures running through great thicknesses of rock. Sometimes these are mere fissures; but quite as frequently there is not only a severance but a displacement of the rocks that have been severed. Beds that were once continuous are now not only broken through, but are left at very different levels on opposite sides of the fissure—many feet, or many hundreds of feet above or below the parts with which they were once continuous. When this is the case, these fractures are called "faults" or "dislocations" by geologists, for which miners in different districts use in addition the terms "slip," "slide," "heave," "dyke," "thing," "throw," "trouble," "check," and other expressions.

The throw of a Fault.—The amount of dislocation measured in a *vertical direction*, produced by a fault, is called its "throw," a fault being said to be an "upthrow" or a "downthrow," or an "upcast" or "downcast," according to the side from which we view it. Its amount is stated in fathoms, yards, or feet, measured perpendicularly from the surface, provided the surface be horizontal, from a given horizontal plane if it be not. If, for instance, a bed of coal, where it is cut by a fault, as at A, fig. 38, be 100 yards from the surface, or from an as-

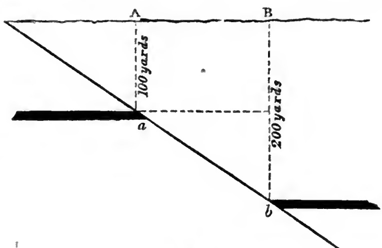


Fig. 38.

sumed horizontal stratum line AB, and the other part of the bed immediately on the other side of the fault, as at b, be 200 yards below the line A B, the throw of the fault is said to be 100 yards, without regard to the distance measured laterally from A to B along the surface, or from a to b along the fault.

In some places especially, in cases where the outcrop of a bed is dislocated at the surface, the distance A B, by which the ends of the beds are separated, is called "the heave" of the fault, though this is sometimes measured along the fault from a to b. In taking accounts from miners as to the characters of faults, it is necessary to be on one's guard, and be quite sure that the sense in which they use these terms is properly understood. In some districts they would speak of the distance A B, measured along the surface of the ground, or the horizontal distance between the ends of the beds, as the "width" of the fault, looking only to the extent of "barren ground" as to that particular bed, and paying no attention to the real width of the actual fissure itself, which might be not more than a few inches, or perhaps even not more than one.

Varieties of Faults.—Faults vary in character and in effect, firstly, according to the nature of the rocks which they traverse, whether they be hard or soft, or an alternation of both; secondly, according to the position of the beds which they traverse, whether these be horizontal, inclined, or contorted; thirdly, according to the direction and number of lines of fracture, their inclination and combination.

Variation in Faults from nature of Rocks traversed.—When faults traverse a mass of rather soft and yielding beds of rock, such as shales and thin sandstones, the fissures themselves are often mere planes of division, just as if the rock had been cut through with a knife.* In

* Dr. Tyndall in his Glaciers of the Alps (p. 317), has a passage describing the first formation of a crevasse upon a glacier, which seems to me highly suggestive of what must occur in the first fracture of the rocks which makes the commencement of a fault. After pointing out that crevasses always commence as "mere narrow cracks which open very slowly afterwards," he says, "on the 31st of July 1857, Mr. Hirst and myself having completed our day's work, were standing together upon the glacier du Geant, when a loud dull sound like that produced by a heavy blow, seemed to issue from the body of the ice underneath the spot on which we stood. This was succeeded by a series of sharp reports, which were heard sometimes above us, sometimes below us, sometimes apparently close under our feet, the intervals between the louder reports being filled by a low singing noise. We turned hither and thither as the direction of the sounds varied; for the glacier was evidently breaking beneath our feet, though we could discern no trace of rupture. For an hour the sounds continued without our being able to discover the source; this at length revealed itself by a rush of air bubbles from one of the little pools upon the surface of the glacier, which was intersected by the newly formed crevasse. We then traced it for some distance up and down, but hardly at any place was it sufficiently wide to permit the blade of my penknife to enter it."

I have observed a somewhat similar effect in the noise resulting from the first crack, and the subsequent slow opening of the fissure when standing on the deck of a vessel that was driven stem on against an ice floe, in order to force a way through it.

Possibly the noises heard during an earthquake may have a similar origin in the cracking

this case, the two contiguous surfaces of the fault are very frequently found to be quite smooth and polished by the enormous friction that has taken place, producing the appearance well known to geologists under the name of "slickensides." In some cases, although the fracture seems quite clean and sharp, yet the beds on each side are traversed by a great number of small, irregular, and discontinuous "slickenside" surfaces, as if a jarring and tremulous grinding motion had been produced in the mass of the beds.

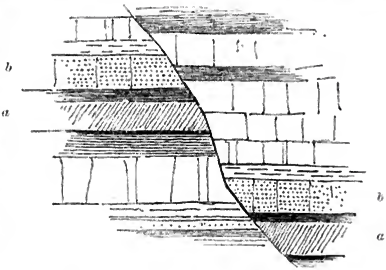


Fig. 39.
Section of faulted beds without distortion.

Sometimes the beds end abruptly without any distortion, fig. 39; but sometimes they seem to have been bent and pulled down along the plane of the fault to a certain extent, as in fig. 40.

In fig. 40, the beds would be said to "rise towards the upthrow," and "dip towards the downthrow;" and this is naturally the most usual occurrence, though I believe not invariable, as there are said to be instances where the very opposite of this takes place, and the beds seem to "rise" to a downthrow fault.

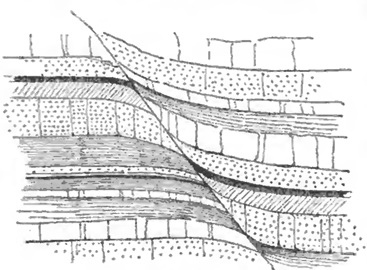


Fig. 40.
Section of beds distorted by fault.

When faults traverse very hard and unyielding rocks, such as thick hard gritstones, hard limestones, or hard siliceous slates, and still more, if they penetrate igneous rocks,

of rocks below the surface, and faults may be afterwards slowly formed by gradual vertical displacement along these cracks deep beneath the surface of the ground, or sometimes even reaching up to it, just as the crevasses afterwards gape slowly at the surface when obeying a differently directed impulse from that productive of faults.

such as granites and felstones, the fissures are apt to be much wider, and often very irregular. If the original fracture shall have taken place not in one plane, but so as to produce two jagged and broken, or uneven and irregular surfaces, with cavities and protuberances as in fig. 41, and these two surfaces slide one over the other, it is very unlikely that they would ever, unless restored to their original position, be made *to fit exactly* so as to close again upon each other throughout their extent. Protuberance might rest against protuberance, or come against a hollow not large enough, or not of the requisite form, to receive it, and thus the two walls of the fissure would be kept partially and irregularly apart, the fissure being closed in some places and open in others. In fig. 41, an uneven fracture having traversed the hard beds A, B, C, D, and dislocation taken place, the result would be the irregular fissure E F.

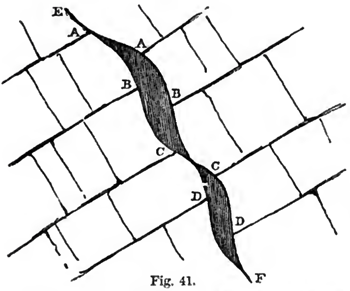


Fig. 41.
Section of hard beds cut by uneven fault, and consequent cavities.

It is true that the grinding process, as the surfaces moved upon each, would often greatly diminish this irregularity, and in soft rocks probably obliterate it ; but in hard rocks it is much more usual to find the irregular openings above described still remaining.

Where alternations of hard and soft beds occur, there may be a combination of the two effects, the fissure being quite closed where soft beds are brought together, or even where soft beds are brought against hard, but more or less open where two hard beds come in contact.

In speaking of open fissures, however, it is by no means intended to assert the frequency of fissures now open and empty. They are almost invariably filled with materials either derived from the ruins of the adjacent rocks at the time of the fracture occurring, or afterwards brought into them.

Some fissures, even in the most soft and yielding rocks, have been kept open, or rather the sides of the fault kept apart, by fragments and debris that were dragged into them at the time of their occurrence. Such fragments, often of large size, are found along the lines of faults both vertically and laterally, for in tracing the line of a fault along the surface of the ground, we often find lumps and patches of the broken

beds, even some yards in diameter, caught by the way, and serving to point out the direction of the fault.

Variation of Faults in effect according to inclination of Beds traversed.—As it is comparatively rare to find beds in a strictly horizontal position over any considerable area, it is necessary to study the effect of faults on inclined beds, and on beds with an inclination varying either in angle, in direction, or in both. If any bed or set of beds "striking" in a given direction, and "dipping" at a given angle, be broken through by a fault, the effect of the vertical "throw" is to produce at the surface the appearance of a lateral "shift."

Let fig. 42 be a horizontal plan of the outcrop of a set of beds, of which we may suppose *a a* to be a limestone interstratified with sandstones and shales, and that they all dip steadily to the north at an angle of 25°, and that these beds are traversed by the fault *b b*, causing a "downthrow" to the east, or an "upthrow" to the west, which is the same thing; then the outcrop of the beds will be farther south on the east side of the fault than they are on the west.

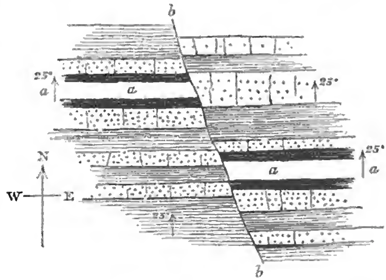


Fig. 42.
Plan of the surface of inclined beds, traversed by a fault which produces an apparent lateral shift.

To render this more evident, let fig. 43 be a diagrammatic section drawn from south to north along the direction of the line of fault, shewing the beds on both sides of it, and let us look only at the limestone *a a*, disregarding the other beds. If we suppose the part (*b*) dropped vertically down to (*c*), and the part (*d*) in the former continua-

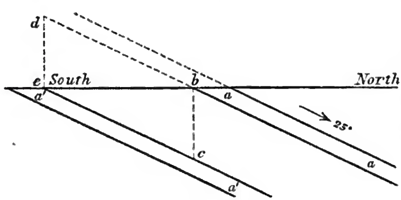


Fig. 43.
Diagrammatic section of fig. 31, to explain the apparent lateral shift of an inclined bed along a horizontal line when it is moved vertically across it.

tion of the bed down to (*e*), it is clear that a vertical throw of the bed *a a* on one side of the fault will place it in the position *á á* on the other side of the fault, the respective outcrops of the two pieces of the same bed being at the present surface of the ground at the points *b e*. In other words, the apparently lateral shift of the outcrop of *a a* in the plan, fig. 42, has been produced by the vertical throw of the inclined beds on opposite sides of the fault. The figure 43 may perhaps be more readily understood if it be copied on a separate piece of tracing paper, and then the tracing paper placed over the figure, so that *á á* should coincide with *d b;* if then the piece of paper be moved vertically down the page, keeping the dotted lines *d e* and *b c* on the tracing paper over those in the woodcut, it will be seen that, while the movement of the paper is vertical, the bed *a a* will travel laterally along the horizontal line from north to south, so that from *b* it will gradually arrive at *e*.

It will be seen that the higher the angle at which the beds dip, the less will be the apparent shift at the surface produced by the same amount of throw. In fig. 44, the angle of inclination is increased to 60°, the vertical throw, or the distance between *b* and *c*, remains the same as in fig. 43; but it is obvious that the apparent lateral shift or distance between *b* and *e* is greatly diminished.

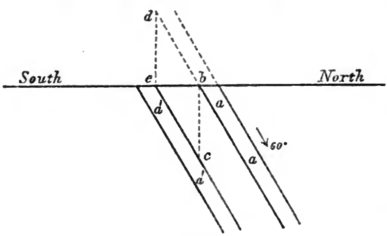


Fig. 44.

This diminution would continue with the increase of the angle of inclination, until the beds were actually vertical, when it is plain that no amount of vertical throw could produce any apparent lateral shifting, for the ends of the beds in the opposite sides of the fault would merely slide up or down along each other. In a set of vertical beds, then, it would be almost impossible to detect a fault, however great may have been the real fissure and dislocation. On the contrary, when the beds lie at a very low angle, a very small dislocation shifts the outcrop of the beds in a very remarkable manner.

It is obvious, from an inspection of figs. 43 and 44, that if we know the inclination of the beds, and the amount of the vertical "throw" of the fault, we may easily calculate what will be the apparent shift of their outcrop at the surface; and if, therefore, we find the outcrop of one, it will be easy to discover the outcrop of the other.

On the other hand, if we know the distance between the outcrop of the beds on opposite sides of the fault, and their angle of inclination, it will be easy to calculate the amount of the vertical "throw," or to discover the depth (or distance, *b c*) at which the one part of the bed will be found lower than the corresponding point on the other side of the fault.

In practice, allowances have to be made for irregularity in the surface of the ground, and for variations in the angle of inclination of the beds, and also for changes in the amount of "throw" in the fault, but in the above consideration of the simplest case lie the elements of much practical utility in mining and other operations. In the Appendix will be found a table, that, among other things, will show the relations between the dip, the throw, and the shift or heave of dislocated beds, pointing out, when any two of these are known, the value of the third.

That this apparent lateral shift at the surface is really due to vertical elevation or depression, may be shewn further by examining its effect on beds thrown into anticlinal and synclinal curves.

Let fig. 45 be a plan in which *a a a* is a bed having a synclinal or basin-shaped depression at S S, and an anticlinal form at A A, dipping, as shewn by the arrows, at an angle of 60° in each direction, and let it be traversed by the fault F F. It is clear that no lateral shifting will account for the places of the broken ends of *a a* on opposite sides of the fault, since they are shifted in opposite directions; while their present positions are easily and obviously accounted for on the supposition of a vertical elevation on the side of the fault marked *u u*, or depression on that marked *d d*, and a subsequent planing down of the whole to one level surface. If we draw two sections parallel to the fault, and on opposite sides of it, one, as in fig. 46, along *u u*, the upcast side, and the other, as in fig. 47, along *d d*, the downcast side, putting in the beds with a dip of 60°, as directed by the arrows in the plan, we should at once see that, in fig. 46, on the upcast side of the fault, the beds will meet below S, at a point much nearer the surface than they

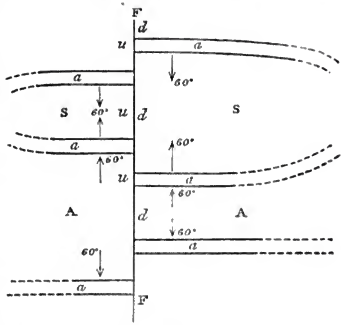


Fig. 45.
Plan of anticlinal and synclinal curve traversed by a fault.

do in fig. 47 on the downcast side; in other words, that the bottom of the synclinal is at a higher level in the first than the last case. In the same way the point over A, where the anticlinal lines would meet if produced, is higher above the surface in fig. 46 than in fig. 47, or the whole of the bed *a a* is more nearly out of the ground in fig. 46 than in fig. 47. It is plain that these appearances are the result of the vertical elevation of the beds on one side of the fault F F in fig. 45, or their vertical depression on the other side of it. The greater the throw the more widely will the outcrops of a synclinal curved bed be separated on the downcast side, and the more nearly will the outcrops of an anticlinal curved bed be brought together, while on the upcast side of the fault the reverse is the case, the outcrops of a synclinal curve will be brought together, and those of an anticlinal will be separated.

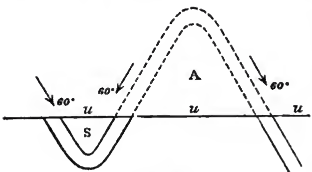


Fig. 46.

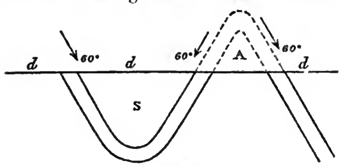


Fig. 47.

When either the angle of the dip or direction of the strike of the beds vary along the course of a fault, its effect upon the position and form of their outcrop becomes equally various. This effect may be still farther complicated by a change in the amount of the "throw" of a fault in different parts of its course.

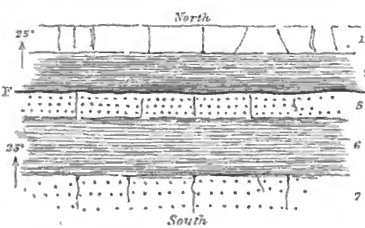


Fig. 48.
Fault along strike. Plan.

The variations in Faults according to their direction, number, inclination, and combination.—We have hitherto supposed the fault to run directly across the beds, or nearly so, but some faults may either, in the whole or in part of their course, run obliquely to the strike of the beds, instead of directly across it, and

instances may occur of dislocations even running along the strike, so as to entirely conceal some of the beds, as in fig. 48, which is a plan, where the fault F F, running directly along the strike of the beds, conceals part of No. 2, the whole of 3 and 4, and part of No. 5, as may be seen by the section, fig. 49.

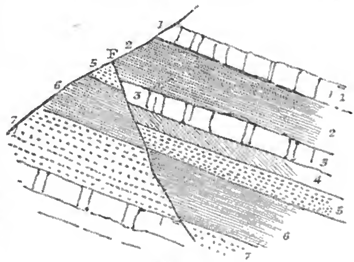


Fig. 49.
Section of fig. 48.

If the magnitude or throw of the fault diminishes in one direction, we should have some of these beds coming out in that direction, as in fig. 50, producing a slight variation in the strike of the beds.

Many other modifications may arise according to the variations in the direction of the faults, with respect to the strike of the beds, or in the amount of their "throw."

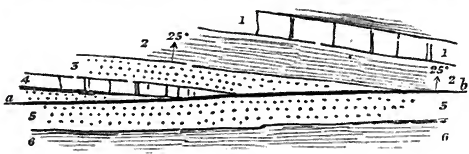


Fig. 50.
Fault along strike, with variation in throw. Plan.

Single or Compound Faults.—The number and association of faults also requires consideration in order to properly understand their effects.

If we suppose a single line of fault only to exist, it involves the assumption that the beds have been bent or bulged either upwards or downwards on one side of the fault, or upwards on one side and downwards on the other.

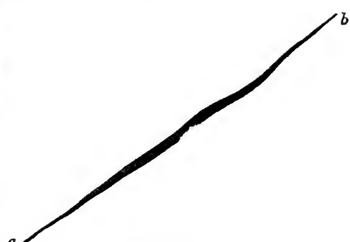


Fig. 51.
Single lined Fault.

If in fig. 51 we suppose the line *a b* to be a crack or fissure traversing a set of beds, or if we suppose it to be a crack in a plank of wood, or any other flexible substance, ending each way without meeting with any other crack or fissure, it is obvious that although the parts will be *severed* along it, they will not be shifted vertically unless some force be applied to push or bend upwards or downwards, as in fig. 52, the part on one side of the fissure, while the other part is held fast, or pushed in the opposite direction.

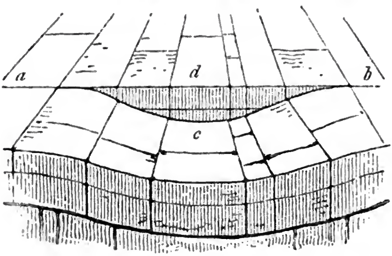


Fig. 52.
Single line fault, produced by bending of beds on one side of fissure.

In fig. 52 some beds are supposed to be cracked by the fissure *a b*, and the part *c* to have been bent down, but we might just as easily have supposed the part *d* bent up, or both operations to have taken place simultaneously. Without some such *bending* no dislocation could have occurred.

Such "single-line faults" have been produced, as is proved in coal-mining. They generally have one, but sometimes more points of maximum "throw" near the centre, and gradually diminish each way till they die out. Not unfrequently they split towards one or both extremities, as is shewn in the plan, Fig. 53, in which the main fault *a b* is

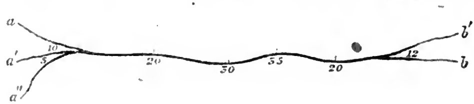


Fig. 53.
Plan of fault splitting at the ends.

seen to be split into three at one end and two at the other. The figures represent the amount of the downthrow at each point, in feet, yards, or fathoms, as the case may be.

The plan of a fault given in fig. 53, is taken from that of the Lanesfield fault in the South Staffordshire coal-field, the figures in that case being yards.

It is possible that this bending of the beds along the line of fault

may occur more than once, so that they may be thrown into undulations, and thus more than one maximum throw may be produced. This undulation, too, may also become so great that the downthrow may change sides, as is attempted to be shewn in fig. 54. This actually occurs in nature sometimes, the fault appearing to die away when the beds come together, and then to set on again with a dislocation in the opposite direction. The fig. 54, however, is to be taken as a mere diagram to help the explanation, and not as an actual representation of nature, where the undulations are rarely if ever so rapid, and are never apparent at the surface of the ground, which, as will be presently shewn, is in all cases a surface of denudation produced subsequently to all subterranean movements. Single lines of fracture are probably in general much more extensive than the actual dislocated spaces, since such bendings and bulgings as are here shewn to be necessary to cause dislocation, would be more likely to occur near the central portions of a fracture than near its extremities.

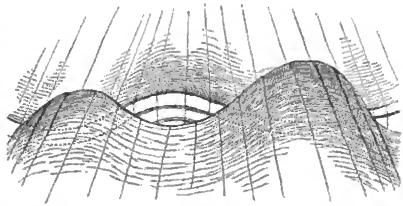


Fig. 54.
Single lined fault, with alterations of throw produced by undulations of beds along it.

When there is more than one line of fracture, the fact of dislocation becomes more easy to understand, since there is no difficulty in conceiving that the angle, or corner of ground included between the intersection of two faults, has been dropped down below, or squeezed up above the corresponding beds on the outside of them. In the plan fig. 55, let *a b* and *c b* be two faults meeting in the point *b*, the included part, *d*, may be either depressed below, or raised above *a b c*. Even in this case, however, the beds on one side or other of the faults must be bent up or down in the direction of *e d*, because, as the two faults end or die out at *a* and *c*, the whole of the beds must be on the same level there, and one part or other must change that level in proceeding in the direction *e d*.

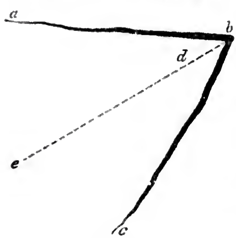


Fig. 55.
Dislocation by two fissures.

There is a modification of this case shewn in fig. 56, where we have one long continuous fault A B, with one or more lateral branches, *c d*, *e f*, *i k*, etc., proceeding out of it, or leading into it, as we may

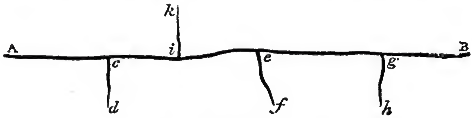


Fig. 56.
Great fault with lateral branches. Plan.

choose to consider them, and either on one or both sides of it. In this case, while the whole mass of ground is thrown down on one side of A B, with respect to the other, the particular portions between *c d*, *e f*, or the corners between any one of them and the main fault may have additional minor dislocations of their own.

A long powerful fault is often composed in the whole, or part of its course, of a number of parallel fissures very close together, along a narrow band of country, breaking the rocks into a corresponding number of steps, as in Fig. 57, which either "throw" all in the same direction, or having some steps in opposite directions, produce a balance of "throw" in one direction, so that it is treated as one wide fault.

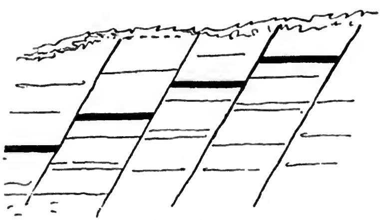


Fig. 57.
Step faults.

In order to have any mass of beds entirely cut off on all sides from those that surround them, and wholly depressed below, or raised above them on every side, it is obviously necessary that we should have at least three straight faults, or one or two curvilinear faults surrounding the fractured piece of ground. Such completely separated masses of ground let in bodily among a strange set of beds may possibly occur in nature, though they are very rarely to be met with. No case of the kind ever came under my own personal observation ; supposed instances at Bonmahon, in County Waterford, being now believed to be capable of another explanation.

Relation between the inclination of a Fault and the direction of its

Throw.—Faults and fissures are sometimes vertical, as at A, fig. 58, but more commonly inclined at various angles, even so low in some instances as 20°, as at B, fig. 58.

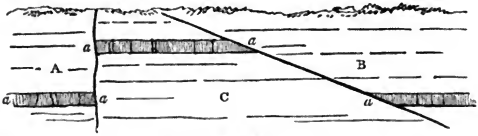


Fig. 58.
Varied inclination of faults, and relation between the "hade" of a fault and the direction of its throw.

In speaking of the inclination of a fault, it is better not to use the term "dip" as if it were a bed, but to adopt that of "hade" or "underlie." In inclined faults, and it almost always happens that faults are inclined, there is one nearly invariable rule, which is, *that the fault "hades" or "underlies" in the direction of the downthrow.*

As a corollary of this rule also, another equally important one may be stated, namely, that however inclined may be the fault, *no part of any bed will ever be brought vertically under another part of it*, and therefore superior beds can never be brought *by any* fault under those originally below them.

Small exceptions to these rules may sometimes occur in rare instances; when they do, the fault that produces them is called a *reversed fault.*

In fig. 58, for instance, the fault between B and C hades under the downcast piece of the bed (*a a*); and it is obviously impossible for a vertical fault, or one inclining in the proper direction, to bring any part of the bed *a a* vertically beneath another part, and consequently no part of the beds above *a a* can ever be brought underneath it, as they would be in the imaginary and exceedingly rare case in fig. 59.

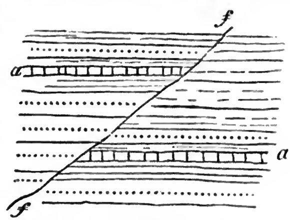


Fig. 59.
Reversed fault: of very rare occurrence.

I have never myself met with any exception to this rule, except on a very small scale, and where it might easily happen that the exception was more apparent than real, the apparent inclination of the fault being merely a local bend or indentation in a vertical or nearly vertical fault. A case of real occurrence of a "reversed fault" has,

however, been lately described by Mr. G. H. Kinahan, from the information of Mr. Edge, as to the position of some beds in a colliery in the Queen's County, Ireland. (See *Journal Geol. Soc. Dub.*, vol. viii.)

The reason of this rule is sufficiently easy to understand when we come to look at faults on the large scale. Suppose that in the diagram, fig. 60, we have a section of part of the earth's crust, of which

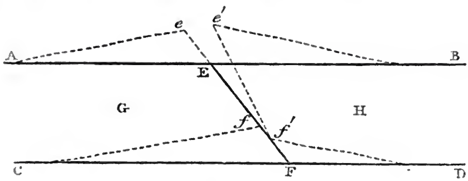


Fig. 60.

A B is the surface, and C D a deep-seated plane acted on by some wide-spread force of expansion tending to bulge upwards the part A B C D. If, then, a fracture take place along the line E F, it is obvious that the expanding force will on the side of A C have the widest base, C F, to act upon, while it will have a proportionately less mass to move in the part A E C F which grows gradually smaller towards the surface, than on the other side of the fault, where with the smaller base F D, the mass F D B E continually grows larger towards the surface. The mass G will consequently be much more likely to be raised into the position A *e* C *f*, than the mass H into the position D *f'* B *é*, the elevation of which could hardly take place without leaving a great open gap along the line of fault between F E and *f' é*, and, moreover, without leaving the projecting piece *é* overhanging without any support.

This is yet more clearly perceptible if we suppose two such fissures,

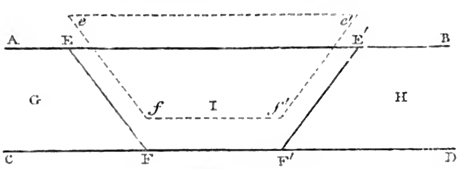


Fig. 61.

as in fig. 61, inclining towards each other, since if we suppose the included piece I to be elevated into the position indicated by the dotted lines it becomes utterly unsupported ; unless we suppose huge dykes or

ejections of igneous rock to issue out along each fault, which would remove the case from the class of fractures we are at present considering.

In another case which we might imagine, that of two parallel faults inclining in the same direction, as in fig. 62; the included piece I might be elevated without leaving an open fissure, but still the part *I* would overhang in an unsupported condition, and the enormous friction along two sides of the piece I would have to be overcome. I am not aware indeed of any case similar to this having been even supposed by any one.

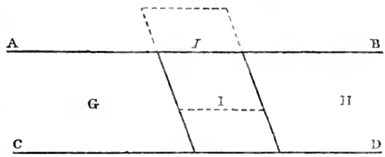


Fig. 62.

Professor H. D. Rogers, in his paper on the "Laws of Structure of the more disturbed Zones of the Earth's Crust" (*Trans. Royal Soc., Edin.*, vol. xxi. p. 3), in describing faults along the axes of anticlinal curves, where inversion has taken place on one side of the anticlinal, speaks of the uninverted part of the anticlinal having been thrust up the inclined plane of the fault, over some of the inverted beds, as in fig. 63.

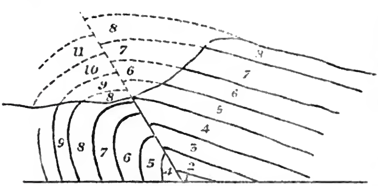


Fig. 63.
Inversion, with reversed fault.

Professor Rogers does not allude to the fact of this form producing a *reversed* fault, nor is it quite clear in his paper whether the structure thus described has been absolutely observed in sections, or is merely introduced hypothetically as an explanation of certain phenomena. If actually observed, a detailed description of the locality would be interesting, neither am I prepared to combat the hypothesis, if it be one, since it is just in such greatly disturbed districts that "reversed" faults are likely to occur.

I believe that the rule as to the relation between the inclination of a fault and the direction of its throw might be still further generalised so as to include also the direction of its "heave" or "shift," so that the rule might be stated thus:—"*No fault traversing any set of beds will make an acute angle with the same bed on both sides of the fault.*"

The position of the beds shewn in fig. 59, in which a bed *a a* is

cut by a fault F F so as to have an acute angle on both sides of it, is then generally an impossible one (except as a small local occurrence in a greatly disturbed district), whether we regard the figure as a vertical section or a horizontal plane.

Trough Faults.—Faults ordinarily extend indefinitely downwards. We cannot comprehend the possibility of fracture and displacement having taken place in any uncontorted set of beds without all those below having been equally disturbed, unless we come to a part where another fracture occurs, producing an equal amount of displacement in an opposite direction. This junction between two opposite faults produces what is often called a "trough," the faults being called a "pair of faults." The opposite faults of a trough may be either unequal in "throw," as *a c* and *b c*, in the trough A, or equal, as *d e*, *f e*, in trough

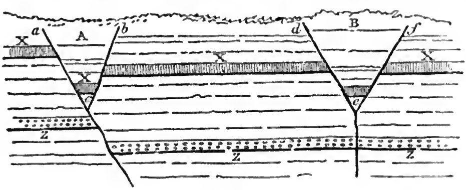


Fig. 64.
Trough Faults.

B. In the former case, the displacement affects the whole mass of the surrounding rock, as may be seen by tracing the bed X through the dislocations; in the latter case, it only affects the mass B, which is included between the faults. In the latter case, we may see that the bed X on the outside of the trough B is on the same level on both sides.

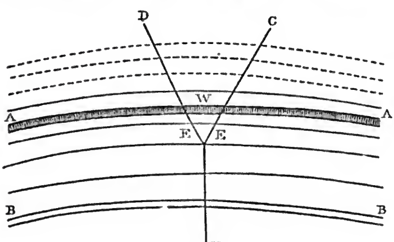


Fig. 65.

The mode of explanation of these trough faults that seems to me the most probable, if not the only one, is the following:—Suppose the beds A A, B B, etc., to have been formerly in a state of tension, arising from the bulging tendency of an internal force, and one

fissure, F E, to have been formed below, which on its course to the surface, splits into two, E D and E C, as in fig. 65. If the elevatory force were then continued, the wedge-like piece of rock W, between these two fissures, being unsupported, as the rocks on each side separated, would settle down into the gap, as in fig. 66. If the elevatory action were greater near the fissure than farther from it, the single fissure below would have a tendency to gape upwards, and swallow down the wedge, so that eventually this might settle down, and become fixed at a point much below its previous relative position. Considerable friction and destruction of the rocks, so as to cut off the corner *g h* (fig. 66) on either side, would probably take place along the sides of the fissures, and thus widen the gap, and allow the wedge-shaped piece W to settle down still farther.

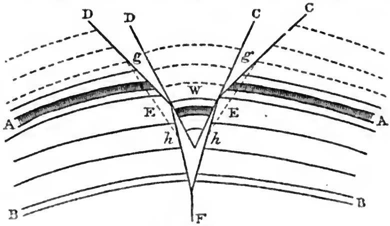


Fig. 66.

When the forces of elevation were withdrawn, the rocks would have a tendency to sink down again and resume their original positions, but these newly included wedge-shaped, and other masses, would no longer fit into the old spaces, so that great compression and great *lateral* pressure might then take place.

The reader must recollect that the figs. 65 and 66 are mere diagrams to assist his comprehension, and not actual representations, in which there would necessarily be introduced a much greater amount of irregularity and complexity. This may be seen by an inspection of fig. 67, which represents the commencement of a trough fault, in the middle of the Thick coal of South Staffordshire. This was carefully drawn to scale by a competent observer, Mr. Johnson of Dudley, from the side of a "gate road" in the Victoria colliery at West Bromwich. It shews the arching of the beds and their fracture by numerous small fissures on each side of the main fracture, where the beds gaped and let in a wedge-shaped piece of the beds above. On each side of this "trough fault" the coal marked B B was reduced by pressure to a state resembling "a paste of coal dust and very small coal," while the parts marked C were uninjured. The total thickness of the coals, which here constitute the Thick coal is about ten yards, and the length of the gate road shewn in the figure about 100 yards. (*Mems. Geol. Survey*, *S. Staff. Coalfield*, 2d edit., p. 194.)

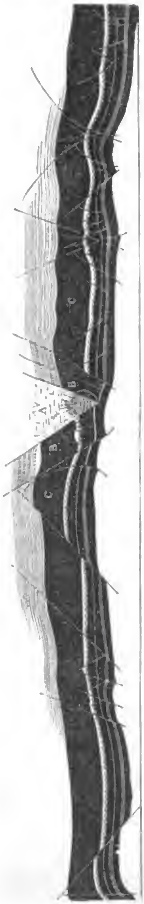


Fig. 67.

Section in the thick coal of South Staffordshire. It illustrates the arched position which was given to the beds, the cracks that were formed in them, and the dislocations that took place, in consequence of the elevation, and as the fractured pieces endeavoured to settle down on the forces of elevation ceasing to act.

It seems certain here that the beds were arched and cracked in the centre, so as to include the wedge-shaped mass A, and that on settling down again that piece prevented the beds regaining their former position. The vertical downward tendency then resulting from the pressure of the superincumbent mass would here be transferred to a lateral pressure, tending to crumple and dislocate the beds on each side.

Lateral Pressure.—We have already seen that the appearance of lateral motion having taken place in beds is often a fallacious one. We have, however, in the above considerations, a true cause of lateral pressure, which may sometimes operate on a far larger scale than the little example just quoted. The vast anticlinal and synclinal curves into which great mountain masses are usually thrown may originate in very much the same way* as the minor cracks and squeezes in this case.

Connection between Faults and Contortions.—As the result of my own experience, I may affirm that it is comparatively rare to find a district greatly contorted, and also traversed by large faults; and, on the other hand, wherever a district is much broken by faults, the masses of ground between the faults are usually but slightly bent and contorted. This is what we should *à priori* expect to be the case, since, if the internal forces of disturbance acting upon a portion of the earth's crust succeed in breaking it through before they bend it, the further result will be most likely to increase the dislocations rather than to

* The reasoning above given was worked out during the survey of the South Stafford coalfield in 1847 and 1848. I have lately observed that Professor Phillips, in his account of the Malvern Hills, in the second volume of the Memoirs of the Geological Survey, p. 142, had arrived at similar results by similar reasoning some years before.

bend the parts between them, while in those parts where they do not succeed in causing fractures the whole force will be expended in producing a bending and curvature in the rocks.

This is true both of different areas and of different depths in the same area, since great convolutions in the lower parts of the earth's crust will almost necessarily result in fractures and dislocations of the parts above.

Instances do occur of both dislocation and contortion in the same area, but if the contortion be great the dislocations are usually few and small in proportion ; and if, on the other hand, the dislocations be of great number and amount, the contortion is small, either in amount or in extent, when compared with that of the dislocation.

Vertical Extension of Faults.—We have already seen, in tracing faults superficially along what may be called their lateral extension, that it is impossible to conceive displacement to occur except in consequence of a second fault meeting the first, or in consequence of a bulging of the beds along a part of the line of the fault.

Similar reasoning will apply to the vertical extension of a fault.

Mr. W. Hopkins has shewn us that fractures in the crust of the globe have taken place in obedience to certain mechanical or physical laws. If a tract of country of indefinite length and breadth, composed of a set of nearly homogeneous beds, supposed to be originally horizontal, and nearly equally tenacious all over, be acted on by an expansive force from below, such as an elastic gas or a molten fluid would exert, those beds will be strained so as to tend towards bulging upwards, until a number of parallel fissures are formed, commencing at points below the surface, and running up to it. They may be crossed either then or subsequently by another set of parallel fissures at right angles to the first set. These are the normal results which may, in actual fact, be complicated by many irregularities arising from conditions different from those which were assumed.—*Trans. Camb. Phil. Soc.*, vol. vi., p. 1.

It seems to follow from these results, that for displacement to have taken place among the fractured masses, two or more faults should meet below, so as entirely to sever the masses from each other, and allow of unequal motions being communicated to them, or that faults should gradually end downwards on the surfaces of highly curved, undulated, and contorted beds.

Connection between Intrusion of Igneous Rocks and Production of Faults.—The intrusion of igneous rock may in some instances increase the amount of dislocations ; but the student must be on his guard against attributing to local intrusion of igneous rock, effects of elevation, or contortion, or fracture, which are not due to it. The intrusion of igneous rock among other masses is itself a result and not a cause of disturbance. The disturbances of stratified rocks are generally owing

to very widely extended accessions of heat expanding large masses of rock of all kinds simultaneously over great spaces, and the subsequent contractions when that heat is diminished or taken away. Small local intrusions of igneous rock may act as stays and wedges to prevent the dislocated beds settling back into their former places, but such intrusion during widely spread disturbance seems rather to have been the exception than the rule.

When we come, indeed, to consider large intrusions of great granitic masses into the rocks above them, we see a fertile source of dislocation, first, by the expansion of the superior rocks from the mere irruption of the bulk of the molten mass, and afterwards from contraction in consequence of the cooling of that mass, which contraction, as we have already seen, p. 96, might amount to even one-fourth of its bulk.

Where any large mass of matter, too, has been erupted or ejected over the surface of the ground, the withdrawal of its bulk will have tended to leave a void space in the interior, which, if it were not filled up with other igneous matter, would be followed by subsequent sinkings and dislocations of the rocks over it.

Masses of igneous rock, however, whether contemporaneous with the beds in which they lie, or subsequently intruded into them, wherever they spread over a considerable area, seem to be just as much affected by the faults of the district as any of the other rocks.

CHAPTER XIV.

CLEAVAGE AND FOLIATION.

We have now examined three kinds of divisional planes traversing rock —those, namely, which we might call *congenital*, or planes of lamination and stratification ; those which are necessarily *resultant* on consolidation or joint planes ; and those which we may term *accidental*, such as faults. There is yet another kind to be described, which we may call *superinduced* planes of division ; and these are planes of "cleavage" and "foliation."

Fig. 68.

Portrait of a block of variegated slate about 18 inches high, from Devil's Glen, county Wicklow. The crumpled horizontal bands are the beds, the fine perpendicular striæ in front, are the cleavage planes, the fine lines on the darkened side merely represent *shadow*, and must not be taken for planes of division in the rock like those in the front which do not pass through the white bands.

Slaty Cleavage.—By "cleavage" or "transverse" or "slaty cleavage," as it is sometimes called, we understand a tendency in rocks to split into very thin plates, having a certain given direction over wide areas independently of any original lamination or stratification of the rocks. It is a structure which is most especially remarkable in clay slate, but is sometimes apparent in sandstones and limestones. Where it exists it is always most perfect in the finest grained rocks, splitting them into an indefinite number of thin leaves or plates, perfectly smooth and parallel to each other. The coarser the rock, the fainter, the wider apart, and the more rough and irregular do the cleavage planes become.

In fig. 68 is shewn a block of slate consisting of alternations of fine purple and rather coarser green and whitish beds, which have been puckered and crumpled. The finer grained and thicker beds are perfectly cleaved by planes cutting directly across them parallel to the dark side of the block, which is itself a cleavage plane, while the coarser parts shew less tendency to split in that direction, except at wider irregular intervals.

This cleavage may either coincide with the original lamination of the rock, or cut across it at any angle. When it cuts across the bedding of the rock, the original lamination, or tendency to split along the planes of deposition, is generally obliterated, the laminæ being sealed up, or, as it were, welded together. This cementation of the original lamination is not quite invariably the case. I have met with at least one instance where the rock, an indurated shale, split as readily along the original lamination as along the cleavage planes, and was thus minced into long, needle-shaped spiculæ of slate.—(*Report of Geological Survey of Newfoundland*, p. 75.)

Transverse cleavage in sandstone usually divides the rock into coarse slabs only, the upper and under surfaces of the sandstone often breaking into dog-toothed indentations. In traversing conglomerates, the cleavage planes leave the pebbles standing out in relief, and do not cut through them as joint planes do.—(*Professor Sedgwick*.)

Cleaved limestone generally has the original bedding greatly obliterated and obscured; the slabs are thick and uneven, and their surfaces often coated by argillaceous films, sometimes giving to the cleavage the exact appearance of bedding.

Among trap rocks, some very fine-grained felstones are occasionally affected by cleavage, and fine-grained trappean ashes are often so affected.

In passing through beds of different texture, the cleavage planes often vary their angle a little, having a tendency to cut more perpendicularly across the coarser than the finer grained beds. When the inclination of the cleavage planes and that of the original planes of lamination become nearly coincident in any locality, they sometimes appear to coincide entirely, as if the cleavage went a little out of its way, as it were, to coincide with the bedding.

The finest and largest roofing slates seem to be those of a bluish, gray or pale green colour. Where they become either very red or quite black, they are more brittle, and more readily decompose, owing probably to the presence of peroxide of iron in the one, and carbonaceous matter in the other. Bands of colour, such as faint red, green, white, or gray, may sometimes be observed on the sides of slates, often coinciding with slight changes of grain or texture. These, which are called the "stripe" of the slate by Professor Sedgwick, mark its original stratification. The

bands in the block, which is figured in fig. 68, shew this stripe very well. Irregular blotches, however, of different colours, occasionally occur; and sometimes even pretty regular broad bands of colour are to be seen, which do not coincide with the bedding, but go sometimes directly across it, as proved by beds of sandstone interstratified with the slate. Care must be taken, therefore, in field observations, not to rely too implicitly on mere bands of colour in slate rocks.

Direction of Cleavage Planes.—The direction of cleavage planes is generally constant over considerable areas, retaining the same compass-bearing through whole mountain chains, or across large countries, without paying any regard to the contortions and convolutions of the rocks. One of the best examples of this steady direction in the strike of the cleavage planes is the south of Ireland, over the whole of which, from Dublin to the Mizen Head and the Dingle Promontory, the direction of the cleavage seldom varies 10° from East 25° North, whatever rocks it traverses, and however different these rocks may be in lithological character and geological age. A few local exceptions, in which the cleavage had a strike to the South of East and West of North, have, however, lately been observed.

This steady direction generally coincides with that of the main lines or axes of elevation and disturbance which traverse the district, and consequently with the "strike" of the beds.

In North Wales the strike of the cleavage in the Snowdon chain is generally N.E. and S.W., dipping sometimes to the N.W. and sometimes to the S.E. at high angles (see fig. 69).

Fig. 69 is taken from one in Phillips' Report on cleavage in the Proceedings of the British Association for 1856, being an extension of one previously given by Professor Sedgwick, running N.W. and S.E., through the Snowdon Chain; the spectator looking N.E. In this section, the beds *c*, *c*, *c*, are conglomerates, the other beds being parallel to them, and the fine striæ are cleavage planes striking with the beds to the N.E., but cutting them across in the direction of the dip; for while the beds undulate at various angles, the cleavage dips N.W. at 80° or 85° from A to B; S.E. at 80° to 85° from B to C; and 80° to the N.W. from C to D.

In the Berwyn chain, where the beds curve regularly round, from a N.E. and S.W. strike along the Bala and Corwen valley, to an East and West strike along the vale of Llangollen, the strike of the cleavage follows with equal regularity, the cleavage planes dipping W. 20° N. at 30° in the country between Bala and Llangynnog, curving round as they approach Corwen, and striking either due E. and W., or E. 5° N. and W. 5° S., on both sides of the Dee, between Corwen and Llangollen, with a dip almost invariably to the North at a high angle.

In a hill called Moel Faen, between Llangollen and the head of the

vale of Clwyd, near Bwlch Rhiwfelyn, the beds are bent into a synclinal curve, so as to dip north on the south side, and south on the north side of the hill; while the cleavage preserves its steady dip to the north at about 60°. The consequence is that where the dip of the beds and that of the cleavage coincides, the rock makes admirable flags, which are largely quarried, while on the other side, where the cleavage crosses the bedding, slate is produced and quarried for roofing purposes.

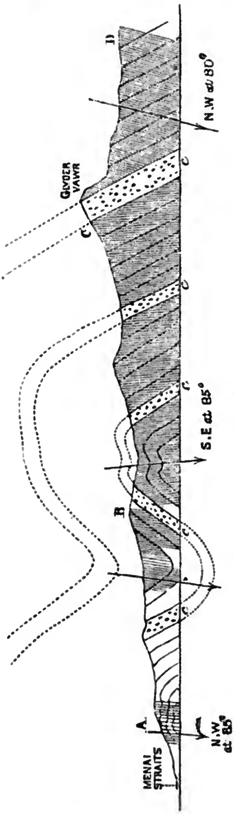


Fig. 69. Section across the Snowdon chain, shewing cleavage cutting across beds.

The inclination of cleavage planes varies from the perpendicular to within a few degrees of the horizontal, but has no apparent reference to the dip of the beds. Mr. Sharpe gives 10° to the W.N.W., as the dip of the cleavage of the Tintagel slate in Cornwall. Round the head of Bantry Bay, the cleavage planes are in some places at as low an angle as 20°, in others are perpendicular, while they everywhere retain the same strike of about E.N.E. and W.S.W.

Professor Sedgwick was the first to systematically observe and describe the phenomena of slaty cleavage. His observations will be found in the *Transactions of the Geological Society*, vol. iii., on *The Structure of large Mineral Masses*, and also in his *Introduction to a Synopsis of the British Palæozoic Rocks*, 3d Fasciculus, p. 33. In the latter, he gives the following as the results at which he had arrived:—

"1st, That the strike of the cleavage planes, when they were well developed, and passed through well-defined mountain ridges, was nearly coincident with the strike of the beds.

"2d, That the dip of these planes (whether in quantity or direction) was not regulated by the dip of the beds, inasmuch as the cleavage planes would often remain unchanged, while they passed through beds that changed their prevailing dip or were contorted.

"3d, That where the features of the country or the strike of the beds were ill defined, the state of the cleavage became also ill defined, so as sometimes to be inclined to the strike of the beds at a considerable angle.

"4th, Lastly, that in all cases where the cleavage planes were well developed among the finer slate rocks, they had produced a new arrangement of the minutest particles of the bed through which they pass."

Origin of Cleavage.—One of the most striking effects of cleavage is the distortion it produces on fossils or other small bodies embedded in the rocks, lengthening and pulling them, as it were, in the direction of the cleavage, and contracting them in the opposite direction. Relying on these facts, which were first distinctly noticed by Professor Phillips, Mr. Sharpe attributed the production of cleavage to the action of great forces of compression squeezing the particles of rock in one direction, and lengthening them in the opposite.—(*Quarterly Journal Geological Society*, vol. iii. p. 87.) Mr. Darwin, also, from his observations in South America, formed similar ideas as to the origin of cleavage, and speaks of cleavage planes as being probably parts of great curves, of such large radius as that any portions of them that can be seen at one view appear to be straight. More recently, Mr. Sorby, resting on the fact of beds of sandstone which occur in slate being contorted, and their dimensions being contracted at the sides and expanded at the tops and bottoms of the curves, the axes of which curves coincide in direction with the cleavage planes, while the beds of slate above the sandstone are little or at all bent, shews that the particles of the slates must have been compressed at right angles to the cleavage planes, and lengthened along them, so as to allow of their being squeezed into the same contracted space as the sandstones, without much bending of the surfaces of the beds.—(See *New Philosophical Journal*, 1853, vol. lv., p. 137; or *Lyell's Manual*, 5th edition, p. 611.)

By microscopical examination, Mr. Sorby found that the minute particles of clay-slate were either lengthened in the direction of the cleavage planes, or that those minute particles, which were of unequal dimensions, were so re-arranged as that their longer dimensions coincided with the planes of the cleavage. He did not suppose that the existence of peculiarly shaped particles was necessary to the production of cleavage, he merely used them as tests to shew that the particles had been re-arranged by the action of the pressure to which he attributed the cleavage.

Dr. Tyndall subsequently investigated the subject, and produced perfect slaty cleavage artificially, in clay and white wax, and other substances, by subjecting them to pressure under conditions which allowed of their expansion in directions at right angles to the pressure. His results are given in the *Philosophical Magazine*, vol. xii., and in a lecture to the Royal Institution now published in the appendix to his work on Glaciers.

Professor Haughton, in a paper in the same volume of the *Philosophical Magazine*, has deduced mathematically a value for the compression of the rocks, from examining the amount of distortion suffered by fossils in some particular instances in consequence of this compression.

A second cleavage plane cutting across the first at right angles, and also across the bedding, is described by Mr. Sharpe in his second paper on cleavage in the *Geological Journal*, vol. v., p. 3, and was also long before observed and mentioned by Professors Sedgwick, Phillips, and others. Mr. Sharpe attributes this likewise to compression.

Professor Sedgwick at one time thought that he could perceive a tendency to a symmetrical arrangement of the inclination of the planes of cleavage with respect to the axes of lines of elevation, the dip of the cleavage being inwards on each side of the mountain ranges. He afterwards, however, saw reason to abandon this conclusion. Mr. Darwin speaks of the fan-like arrangements of the cleavage planes which have been described by Von Buch, Studer, and others ; and Mr. Sharpe says that this apparent fan-like arrangement is due to parts of two contiguous curves meeting where their adjacent sides become perpendicular. But we must refer the reader to his papers on this subject, in the third and fifth volumes of the Journal of the Geological Society before quoted, and in the Philosophical Transactions for 1852.

In the Proceedings of the British Association for 1856, will be found the first part of a Report by Professor Phillips on this subject.

It seems now to be conclusively established that slaty cleavage which thus gives to large parts of the crust of the earth a structure almost as regular and symmetrical as that which determines the perfect facets of a crystal, is the result of the compression produced by the mechanical forces which have acted on those parts.

The slates which cover our roofs, or on which as schoolboys we learnt to cypher, have been thus elaborated. True slate, then, is only to be found in districts which have been thus forcibly acted on.

Time of production of Cleavage.—Slate occurs chiefly in or near to mountain chains or places which have the structure if not the altitude of mountains, and is found in all parts of the world, and in formations of all geological age.

In the British Islands, indeed, slate is found almost solely in the

Palæozoic rocks, but the Andes of Chili and Terra del Fuego, contain clay slate of Cretaceous age, and the black slates of Glarus in Switzerland, which are formed by as true a slaty cleavage as any in Wales, are of recent Tertiary age.

When running geological sections in North Wales, I was occasionally struck by the fact of a sudden change in the strike and dip of the cleavage occurring immediately after crossing a fault. It seemed to indicate that some of the faults, at least, had been caused subsequently to the cleavage, and that blocks of country had been so shifted by the dislocations, that the cleavage planes no longer lay in their original positions with respect to the horizon and compass bearings. In making observations on the relations between cleavage and mountain masses, this is a possible source of error which may have to be guarded against.

Surface disturbance of Cleavage Planes.—The dip of the cleavage, especially, is very easily mistaken, unless it be observed in very clear and deep excavations. Superficial causes have frequently affected and sometimes completely inverted it to very considerable depths, as may be seen in fig. 70.

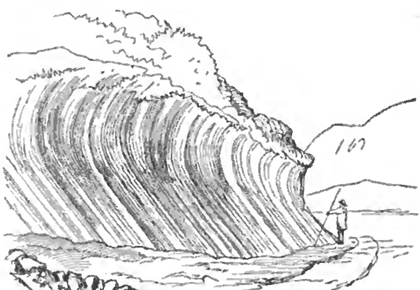


Fig. 70.
Surface bending of cleavage planes.

When these superficial bendings of slate occur on steeply inclined ground, they may perhaps be referred to the action of gravitation on substances loosened by weathering, or the "weight of the hill" as it has been called. In other cases, their origin is more obscure, and I have seen one instance in North Wales, where, on the horizontal surface of an isolated boss of rock, the slates were so sharply and abruptly bent back and laid nearly flat, and partly consolidated in that position, as to

give the idea of its being due to some sudden and great force, such as the grounding of an iceberg.*

Foliation.—The technical meaning of this term originally suggested by Professor Sedgwick in his paper on the mineral structure of large masses before referred to, and since adopted by Mr. Darwin in his volume on the Geology of S. America, is a "separation into layers of different mineral composition," while cleavage means only a "tendency to split" in a mass of the same composition. Foliation, however, even when it coincides with the original lamination of a bed, is nevertheless a superinduced structure.

In examining a specimen of a true schist or foliated rock, and comparing it with one of shale made of the same materials, arranged in laminæ merely by the act of deposition, the difference is at once perceptible, although it is not easily described in words.

In a "foliated" metamorphic rock, such as mica schist or gneiss, the different minerals are more perfectly separated from each other, and each mineral has more of its particles blended together into continuous plates (folia), than in an unaltered sandstone or shale in which the particles exist as distinct grains or flakes. The whole of a foliated rock has a firmer texture, and a cleaner and much more glistening and crystalline aspect, and the foliated structure is sometimes carried out to the extent of making actually crystalline layers. Sometimes even large distinct crystals of one or other mineral traverse the folia, and occasionally the foliation is more or less lost in, and obliterated by, the development of the crystalline structure. The so called protogine of the Alps, seems to be an example of the latter case, which often becomes nothing more than a bed of a species of granite, with a coarse "grain," parallel to its upper and lower surfaces, and to the adjacent beds of the less intensely altered rocks.

The foliation of the schists appears in many cases to coincide with the planes of cleavage, and thus to be arranged in parallel layers over large districts with a strike and dip altogether independent of the original lamination and stratification of the rocks.

Professor Sedgwick is of opinion that the foliation usually coincides with the cleavage, and is merely a further development of the same process, an opinion in which he is supported by Mr. Darwin and the late Mr. Sharpe.

Professor Sedgwick, in speaking of cleavage, says, that the cleavage laminæ "are coated over with chlorite and semi-crystalline matter, which not merely define the planes in question, but strike in parallel flakes through the whole mass of the rock."

* Without intending to impeach the accuracy of any recorded observations, I yet cannot feel sure that many even of my own registered observations on cleavage in different localities may not be affected by errors of the kinds alluded to above.

Mr. Darwin's Observations on the Foliation of S. America.—Mr. Darwin, in the 6th chapter of his Geological Observations on South America, has some excellent remarks upon this subject. He says (p. 163)—"The fact of the cleavage-laminæ in the clay slate of Tierra del Fuego, when seen cutting straight through the planes of stratification, differing slightly in colour, texture, and hardness, appears to me very interesting." He observed in Chili, "some distinct thin layers of epidote, parallel to the highly inclined cleavage of the mass." He then goes on to remark, with respect to the foliation, "as in the case of cleavage-laminæ, the folia preserve over very large areas a uniform strike, thus Humboldt* found for a distance of 300 miles in Venezuela, and indeed over a much larger space, gneiss, granite, mica, and clay-slate, striking very uniformly N.E. and S.W., and dipping at an angle of between 60° and 70° to N.W.,—it would even appear from the facts given in this chapter, that the metamorphic rocks, throughout the north-eastern parts of South America, are generally foliated within two points of N.E. and S.W. Over the eastern parts of Banda Oriental, the foliation strikes with a high inclination very uniformly N.N.E. to S.S.W., and over the western parts in a W. by N., and E. by S. line. For a space of 300 miles on the shores of the Chonos and Chiloe Islands, the foliation seldom deviates more than a point of the compass, from a N. 19° W., and S. 19° E., strike." He then proceeds to state, that the angle of the dip in the foliated rocks is generally high, but variable, sometimes on one, sometimes on the other side of the line of strike, and sometimes vertical, and then says—

"On the flanks of the mountains, both in Tierra del Fuego and other countries, I have observed that the cleavage planes frequently dip at a high angle inwards; and this was long ago observed by Von Buch, to be the case in Norway; this fact is perhaps analogous to the folded fan like, or radiating structure in the metamorphic schists of the Alps,† in which the folia in the central crests are vertical, and on the two flanks inclined inwards.

"Where masses of fissile and foliated rocks alternate together, the cleavage and foliation, in all cases which I have seen, are parallel. Where, in one district the rocks are fissile, and in another adjoining district they are foliated, the planes of cleavage and foliation are likewise generally parallel."

He sums up his observations as follows—"Seeing then, that foliated schists indisputably are sometimes produced by the metamorphosis of homogeneous fissile rocks; seeing that foliation and cleavage are so closely analogous in the several above enumerated respects; seeing that some fissile and almost homogeneous rocks shew incipient mineralogical

* Personal Narrative, vol. vi., p. 591, *et seq.*

† Studer, in Edin. New Phil. Journal, vol. xxiii., p. 144.

changes along the planes of their cleavage, and that other rocks with a fissile structure alternate with, and pass into varieties with a foliated structure, I cannot doubt that in most cases foliation and cleavage are parts of the same process; in cleavage there being only an incipient separation of the constituent minerals, in foliation a much more complete separation and crystallization."—*Ib.*, pp. 165-6.

Mr. Darwin afterwards seems inclined to refer some of the apparent stratification of metamorphic schists, or their separation into alternating beds of different mineral composition, to a still further development of the foliating process, though he of course does not extend this so far as to include the production of "thick beds of marble," or other distinct rock.

Difference between Cleavage and Foliation.—It would be with unaffected diffidence that I should venture to differ from such a high authority as Mr. Darwin, more especially on a point in which he agrees with my own old master and teacher, Professor Sedgwick, nevertheless, I think that the connection between cleavage and foliation is made too close in the passages above cited. If cleavage be the result of mere mechanical pressure, as seems to be now proved, it is apparently impossible that foliation can be so produced. A mechanical force may readily communicate a mechanical texture or structure to a mass of rock, but it seems impossible to suppose it capable of producing an alteration in the mineral composition of its particles.

It appears to me that the connection between cleavage and foliation, in such cases as those mentioned by Mr. Darwin, is an accidental rather than a necessary one. If rocks already cleaved are acted upon by any agency tending to metamorphose them, and rearrange their particles in separate folia, it is probable that in some cases that rearrangement may take place along the cleavage planes, and in others along those of original lamination.

It may even happen that in some districts both cases may occur, and both perhaps may be mingled in such a way as not to be readily distinguishable, where the metamorphism has become very complete. Moreover, since the cleavage planes usually strike with the principal axis of elevation, and the beds, especially when they approach the vertical position, have necessarily the same general strike, it follows that the cleavage and foliation must necessarily be generally parallel to each other, whether the folia coincide with the cleavage or the stratification. Observations as to the vast thickness of such groups of rock may often be deceptive, since concealed anticlinal and synclinal curves frequently occur in them, the beds being either vertical or inclined in the same direction, on account of one or the other side of the curves being inverted, and the folds often sharp, and either not occurring just at the present surface, or occurring in places where the rocks do not happen to be exposed at the surface.

Districts where the metamorphic action has been very great and very widely spread, such as those of S. America, of the Highlands of Scotland, of Scandinavia or the Central Alps, may be less instructive than others, where the alteration having taken place to a less extent, and on a smaller scale, its nature may be the more readily grasped.

Cleaved and Foliated Rocks of the Leinster district.—Such a district we have in the south-east of Ireland, where one great mass of granite has been intruded into the clay slates of the district, forming a continuous range of granite hills from Dublin Bay to the neighbourhood of New Ross, a distance of 70 miles. Between this range and the coast, other smaller intrusive bosses of granite make their appearance at the surface through the clay slate rocks. The clay slates are dark-gray, blue, or black, but sometimes pale-green, or greenish-gray, with occasinally red or purple bands. They are generally of a dull earthy texture, and without lustre. Small bands of gray siliceous grit frequently occur in them.

Wherever the granite comes to the surface, a belt of slates surrounding it is converted into mica schist, with, in some few places, beds of perfect gneiss. Crystals of garnet, schorl, andalusite, staurolite, etc., make their appearance in these altered slates in greater and greater abundance as they approach the granite. The width of the metamorphosed belt is generally proportioned to the size of the granite mass which it surrounds. Round the smaller granite bosses it is sometimes not more than 50 yards wide; round the main granite mass it sometimes reaches to two miles. It matters not through what part of the slate rocks the granite rises, or which beds strike towards the granite; they are all found to be affected in the same way as they approach it.

In going towards the main granite ridge, it is found sometimes at a distance of two miles from the outcrop of the granite (which is, however, much nearer probably, in a vertical direction), that the slates have acquired a "glaze," as it were, or micaceous lustre, with a soapy feel. This lustre is apparent throughout the mass when the slates are broken, and even when they are ground down into sand or powder. This micaceous appearance increases as we approach the granite, till at last distinct plates and folia of mica are to be seen, and the whole assumes the ordinary character of mica schist, occasionally passing into a kind of gneiss.

Together with the micaceous lustre on the surface of the slates, the rocks often assume the puckered and corrugated structure of mica schist. I at one time thought that this corrugated structure might be a metamorphic one, like the foliation; but on examining localities where small bands of siliceous grit were interstratified with the slates, I found these grit bands to be equally corrugated and puckered. The

structure, then, must be ascribed simply to a mechanical force compressing the rock laterally.

In the great majority of instances, the folia of the mica schist, whether straight or puckered, are certainly parallel to the grit bands, and therefore to the original lamination and stratification of the rock. In these instances, the micaceous folia are largest and best developed. In one case, however, the foliation seemed to run across the bedding, coinciding apparently with the cleavage, as remarked by Professor Ramsay in a similar case in North Wales. In this instance, the micaceous folia were short and discontinuous, being apparently interrupted by the changes of texture or composition in the original lamination of the rock.

Some of the beds of gneiss in this district are obviously beds of sandstone, originally interstratified with the shales, the rocks having all the appearance of interstratified beds of shale and sandstone at a distance, and until they are broken open and found to be perfect mica schist and gneiss. Other gneiss beds are massive and thick-bedded, and contain large crystals of feldspar (apparently orthoclase) becoming quite porphyritic and completely mineralized, but still having a foliation parallel to what is apparently the original stratification of the mass, which in one conspicuous instance (near Graiguenamanagh) is nearly horizontal.—(*See Explanation of sheets* 147 *and* 157 *of the Geological Maps of Ireland.*)

In this instance, then, the foliation was clearly developed along the lamination of the rocks, and had only an occasional and accidental connection with the cleavage.

Good slaty cleavage was observed in the clay slates immediately outside of the metamorphosed band in one or two places, without shewing any appearance of foliation; and not differing from the slaty cleavage seen at a distance from the granite.

I can, however, conceive it quite possible that if the south of Ireland generally were to be greatly depressed into the crust of the earth and deeply buried under other deposits, so as to be brought within the influence of a widely spread action of metamorphism, instead of the mere local action of the granite, that a foliation might be produced in many parts of it coinciding with the cleavage which, as before remarked, is constant to a strike of E. 25° N. and W. 25° S. across the island from one side to the other. When again elevated and exposed by denudation, the rocks might then resemble those of South America in the approximate parallelism of their stratification, cleavage, foliation, and axes of mountain chains.

Relations between Gneiss and Granite.—When treating of the lithological characters of gneiss and granite, an occasional difficulty was mentioned in the distinction between them. Some gneiss, that is to say,

some metamorphosed argillaceous or micaceous sandstone, acquires a lithological structure and texture exactly resembling that of granite. Some granite on the other hand, that is, some unstratified and intrusive mass consisting of a crystalline granular aggregate of feldspar, mica, and quartz, has its components in some parts arranged with a certain parallelism, so as to assume a laminated and quasi-foliated texture, so that lithologically it is undistinguishable from gneiss. It is doubtless impossible in mere specimens, or even in mere blocks of a yard or two in diameter, to distinguish between granitoid gneiss, and gneissose granite. The distinction can only be perceived when their petrological relations, that is, their mode of occurrence and their relations to the surrounding rocks are examined. No true gneiss can send intrusive veins into the surrounding rocks, no true granite will occur in regular beds interstratified with other rocks. It may, sometimes, when a sufficient exposure of the rocks cannot be found, be difficult to determine with respect to any band of granitic-looking rock, whether it be part of a bed or part of a vein. No conclusions should ever be drawn from such uncertain cases.

I believe that the difficulty felt by many continental geologists, of the highest reputation, in drawing a distinction between gneiss and granite, arises from their laying too much stress on the exact mineral characteristics and chemical composition of the rocks, trusting too much to laboratory and museum work, and not studying their relations *in the field*, or not sufficiently relying on their field observations and the conclusions to be drawn from them, when those appear to be at variance with the conclusions of the chemist and mineralogist.

An excellent note on the coincidence between stratification and foliation in the Highlands of Scotland, by Sir R. I. Murchison, and A. Geikie, Esq., appeared as this chapter was being sent to the printer, in the 17th vol. of the Journal of the Geol. Soc., London, part 2.

CHAPTER XV.

DENUDATION.

We have now considered the general effects of disturbing forces in elevating aqueous rocks from the bottom of the sea into dry land, so far as regards the new positions into which these rocks have been thrown, and the divisional planes and dislocations which have been produced in them. We have, however, yet to study some other of the less immediate results of this elevation.

Denudation already tacitly assumed.—The erosive action of the sea-breakers, tides, and currents, along the margin of the land, and that of the atmospheric agencies over its whole surface, has been previously alluded to. In treating of the formation of mechanically formed aqueous rocks, we have tacitly assumed the fact of great disintegration and erosion of previously existing rock, in order to afford the materials of which these mechanically formed rocks were composed. It is impossible for rock to be raised from beneath the sea through the destructive plane of the sea level, without suffering loss in the process, that loss being greater in proportion to the slowness of the movement, or the length of time every successive horizontal margin of ground is kept within the influence of the waves. It is equally impossible for rock to exist as dry land without suffering loss from the action of the atmospheric agencies, that loss also being proportionate to the length of time it remains above the sea exposed to their influence. We are naturally apt to underrate the amount of these erosive agencies, because we see them to be small in any periods of time during which we can observe them, or have them recorded in history. It is just as natural, on the other hand, when we look at the magnitude of the results, for us to suppose that the agencies which were formerly in existence, were much more powerful and destructive than those we now see around us. When, however, we come to reason on the matter, we find it very difficult for any one to imagine what these agencies could have been if they are altogether different from "existing causes;" and equally difficult for any one to suppose existing agencies to have ever acted with much greater intensity than at present, unless we assume the general physical laws of the world (not to say of the universe) to have been different from what they are now. It would seem to be necessary

for instance, to suppose the laws of the attraction of gravitation, and the attraction of cohesion, to have been different from what they now are, if we are to imagine either that the erosive powers of water, and the magnitude and force of waves on the one side, or the disturbing effect of the expansion from heat on the other, produced greatly different effects from those which they now produce. Because such is the balance between the power and the results of all the physical laws and forces that now act upon the globe, that it seems scarcely possible to imagine any change in one without a corresponding change in all the rest. But a change in these laws would also involve a corresponding alteration in the form and structure of organic beings. If, therefore, the forces of denudation had ever been materially different from what they are now, the size of fragments, the modes of accumulation, and the size and structure of fossil animals and plants, would all have shewn traces of that difference. Now, no such general adaptation to altered circumstances is apparent in either the minerals, the rocks, or the fossils of any part of the earth's crust at whatever period it was produced. There appears, then, to be far more extravagance in assuming such great and sweeping changes to have passed over the world, without leaving unmistakeable signs of their occurrence, than in merely allowing the time during which existing causes have acted to be indefinitely extended.

We shall therefore take it for granted, in accordance with the tenets of the Lyellian philosophy, that all geological effects are due to causes such as are now acting in some portion of the globe or other, or to some modification and combination of those causes, such as we may reasonably suppose to take place now and again in the course of the earth's history.

The amount of Erosion must be at least as great as that of Deposition.—To estimate aright the lapse of geological time, the observer, when he glances, for instance, at the bed of the mountain torrent, and sees it encumbered with blocks and boulders, against which the stream is continually fretting, must look forward to the period when this friction of the waters shall have worn down the rocks into fine sand or mud, and carried them onward to the ocean ; and recollect that such a period is but one second of geological time, one beat of the geological clock, and the result of such an action but one stroke of the geological hammer, under whose repeated blows the very mountains themselves shall ultimately be " removed and cast into the sea." He must be prepared to attribute to such seemingly insignificant and slowly acting causes, whether of the river or the breakers of the sea, all the precipitous valleys and ravines of mountain chains, all the erosion of rock which gives to elevated land its cliffs and precipices, its hollowed and indented surface ; and yet greater effects even than these, inasmuch as the very low lands them-

selves are in some cases low only in consequence of mountains having been removed from them. Lyell long ago shewed that the amount of such denudation is to be exactly measured by the quantity of the mechanically formed aqueous rocks, and as our present lands shew us vast sheets of sandstones and clays, hundreds and thousands of feet in thickness, and hundreds and thousands of square miles in extent; and as every particle of these enormous masses of rock is the result of the erosion of previously existing rock, it follows that the amount of denudation must have been just as great as that of deposition. Just as when we see a large building, we know that a hole or quarry must have been made somewhere in the earth, equal, at least, to the cubical contents of the solid parts of that building; so, when we see a vast mass of mechanically formed aqueous rock, we must feel assured that a gap was made somewhere in the surface of the earth equal to the solid contents of those rocks.

Denudation is the production of successive new Surfaces.—This erosion of previously existing rock, and carrying away of the materials, so as to expose a fresh surface, is known to geologists under the technical term of Denudation; a word which refers rather to the fact that a new surface has been laid bare, than to the bulk of the matter removed for the purpose, or the means employed to effect it. The word, however, is none the less applicable on that account, especially if we look on the action as one by which new surfaces are produced (*i.e.*, laid bare) from time to time one after the other over the same area.

All the dry land of the globe has been at one time or another beneath the sea, and the great majority of it consists of beds of rock formed under the sea. The cases, however, in which those beds remain unchanged in everything except mere level, are very rare indeed. They have almost always been tilted, from having been lifted higher in one part than in another, and the uppermost beds, or those last formed beneath the sea, have almost invariably been eroded, and more or less of them destroyed and removed. The only cases, probably, in which we get for the surface of ground the original unabraded surfaces of deposition, are in deltas and the alluvial flats of rivers, or in marshes and lagoons, whether of salt or freshwater origin, and channels are often cut even in these by floods or other irregular action of moving water. In the space left bare at low water on the margin of the sea, we perceive undulations of surface resulting not merely from irregularities in the accumulation of materials, but also from the erosive action of tides and currents. The bottom of the sea is, indeed, anything but a dead flat, as we may see by the soundings marked on charts, and the banks and hollows in the bottom are more or less due to irregularities in the accumulation of materials, but no part of the sea bottom could be raised so as to stand for a time between high and low-water mark,

without having its surface modified in some way by the breakers or tidal currents, and that surface would be still farther modified if it should be subsequently raised above high-water mark into dry land. Even with respect then to the most recently formed beds, and those still retaining their original horizontality after elevation, the surface would undergo some change in passing from a permanent sea-bottom into permanently dry land.

But with respect to still older rocks, this modification of surface is carried out to a greater and greater extent, both in consequence of their having suffered from sea erosion or atmospheric degradation, for much longer periods, and also in many cases because they have been both elevated and depressed more than once so as to have been submitted to repetitions of the processes, those repetitions naturally tending for the most part to render more marked features once impressed, to deepen the hollows of the land, or cut farther back into it, so as to make the slopes steeper and the cliffs loftier, until at last the very substance of the ground so acted on disappears under the process.

The form of all Ground is a sculptured form.—The form then of all ground is a graven or sculptured form carved out of rocks, whether hard or soft, by the action of the upper part of the ocean, and by the rivers and the weather. These instruments combine to form the great surface-carving machinery, and the disturbing force residing in the interior of the earth is the power which thrusts upwards rock, so as to bring it under the action of this machinery during elevation, or withdraws it from its influence for a time by depression, new materials being often plastered over the old surface during the latter period, which are in turn pushed up to be themselves carved into shape.

The surface then of any land, or the form of the ground, is in every case (except in volcanic masses recently ejected, or in such instances as blown sand) the result of the joint action of elevation and denudation, the elevating process being only efficient as bringing the rock within the reach of the denuding action, and never itself producing any direct effect on the form of the ground.

Two kinds of Hills, those of Circumdenudation, and those of Uptilting.—No mountain or hill is anywhere known that can be shewn to have been formed by any *uplifting* action of any kind whatever, subsequently to the production of its own surface and the surface of the surrounding ground. If we except volcanic hills, and hills like sand dunes, we may say that all hills and mountains are one of two kinds, hills of circumdenudation or hills of uptilting.

Hills of Simple Circumdenudation are masses of high ground whose bases are formed of the same rocks as the adjacent low lands are formed of, while their upper parts are not to be found in the immediate low lands. The high ground consists of the parts that have been spared by

the denuding action which has removed the continuation of those parts from above the surface of the low lands.

Fig. 71 is a diagram intended to explain what is meant. It will be seen by reference to it that the hills, whether formed of horizontal or

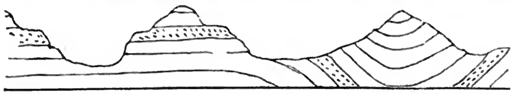


Fig. 71.
Hills of Circumdenudation.

inclined beds, rest on beds which run also below the surrounding low ground, while the higher beds of each hill are not found beneath the low lands surrounding it.

This character, however, is not confined to hills made of stratified rocks, or to hills having the precise form represented in the diagram, fig. 71, which is merely intended to represent some particular instances of a general principle.

Hills of uptilting, on the other hand, are hills not because of the denudation, but in spite of it.

The denudation has been carried out farther on the high ground than the low, and most completely of all, perhaps, on the very highest summits, which are often formed by the lowest of all the beds which succeed in reaching to the surface anywhere in the vicinity.

The rocks have been thrust up highest in the central parts of the mountains, but as soon as the rocks there began to appear at or above the level of the sea, the denuding forces commenced to act upon them and destroy them. As the uptilting force continued, bed after bed was removed from off these central parts, and lower and lower rocks continually exposed to view; the parts of the beds that were spared by the denudation being in this case those that form the low grounds.

The diagram, fig. 72, will help to explain this action, and to shew

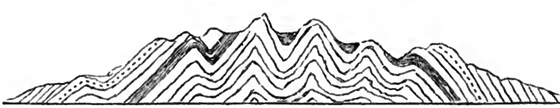


Fig. 72.
Hills of Uptilting.

what is meant by "hills of uptilting" compared with "hills of circumdenudation."

Denudation may have been equally active in both cases, or even

more extensive in the "uptilted" than the other case, but the comparative elevation, or the hilly form of the ground, is in the one caused chiefly by the denudation of the surrounding parts, while in the other case the hills are not nearly so lofty as they would have been if the denudation had not existed.

All the great mountain chains of the world, and many of the smaller ones, belong to the class here spoken of as hills of uptilting.

Valleys, Glens, and Ravines, always caused by denudation.—Valleys of all kinds, except one class to be mentioned subsequently among volcanoes, are valleys of simple denudation. They have always been eroded or worn by the action of moving water gradually cutting away rock from between the higher grounds.

The valleys formerly, and still sometimes, spoken of as "valleys of elevation," and valleys of fracture, if by that term be meant valleys formed solely or chiefly by the violent opening or gaping of the ground upwards, have no existence in nature.

Even among the most violently disturbed and contorted mountain chains, the most rugged chasms and ravines can in no case be shewn to have been the result of such surface fracture of the ground, but are in all cases the result of the erosion of moving water, and are caused by some form of the action here spoken of as denudation.

Action of denudation proved by outcrop of Beds (especially over Contortions) by Escarpments, and by Outliers.—The action of denudation has been so universal, that its very universality often causes the evidence for it to be overlooked.

In examining the outcrop of a set of beds along the surface of the ground, either in "the field" or by aid of geological maps and sections, we must be often struck with the fact that the present terminations of the beds are not their former or original terminations. Beds rise successively to the surface, and end there abruptly, that were once obviously continued beyond or above the present surface of the ground. In fig. 29, p. 235, the beds on the beach and those in the cliff are the same. It is clear that they have been cut down on the beach to their present level, and that before they were so cut down they rose upwards to the same height as those in the cliff. In the same way, those in the cliff itself, and which stretch from it into the land, formerly extended upwards to a greater height than they now do. Now, in many instances we can tell how far they formerly extended upwards. In figs. 32, 33, and 34, the anticlinal and synclinal curves into which the beds are thrown enable us to estimate the amount of this cutting down or denudation for the beds there drawn. In fig. 32, we see that beds 2, 3, 4, bend continuously over No. 1; and we should naturally conclude that beds 5, 6, 7, 8, etc., once equally extended continuously over the anticlinal, A. If we doubted the fact, we should be convinced of it when

we traced them in the map (fig. 33), and found them gradually meeting and continuous over the anticlinal farther towards the north, as represented in fig. 34.

Similarly in the synclinal curve B, though we might suppose by the section, fig. 32, that No. 13 was the highest bed, we should find in the plan, fig. 33, that towards the north it was overlaid by beds 14, 15, etc., as shewn in section, fig. 34; and we should be compelled to conclude that the latter had once been continuous over the whole. The dotted lines in fig. 32 would, if completely carried out, and bed 13 were represented as arching continuously over A, give us the measure of the amount of solid rock removed by denudation from above the present surface of the ground E F, so far as the beds there drawn are concerned; and the dotted lines in fig. 34 shew us that this conclusion may be still farther extended.

It makes no material difference in this reasoning whether we suppose the spaces 1, 2, 3, etc., to represent single small beds of a foot or two in thickness, or groups of such beds, and suppose the whole series, 1 to 15, to represent a vertical thickness of many hundred or many thousands of feet.

Neither would it make any difference in our reasoning, so far as the amount of denudation is concerned, if we were to suppose, in all those cases in which great thicknesses are concerned, that the whole number of beds were never continuous over the anticlinal curves *after* the total amount of elevation had been reached. It is, indeed, most probable, in all cases that, simultaneously with the first arching of the beds, the denuding forces began to act, or at all events that they did so as soon as the rocks were brought up within their reach, and that long before the bed No. 1 attained its present high level over the axis of the curve, more or less of the higher beds 7, 8, or 12, 13, etc., had been removed, and a surface given to the rocks more or less approximating to the surface they at present possess.

Another very clear case in which we can estimate the amount of denudation is that of an "outlier." It often happens that a number of beds, rising at a slight angle from beneath the surface, end in a steep slope or "escarpment," as at A in fig. 73. In front of this escarpment there often rises an isolated hill

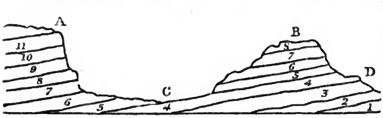


Fig. 73.
Escarpment and outlying hill.

as B, which is called an "outlier." In descending the escarpment, we pass over the edges of the beds 11, 10, 9, 8, etc., in regular succession, and find 4 coming out from beneath them, and stretch-

ing continuously across the intermediate flat or valley, and forming the base of the hill B; and on ascending the side of B, we find the very same beds 5, 6, 7, 8, resting on each other in the same order as we saw them in the escarpment A, and at the same angle of inclination, so that the conclusion becomes irresistible that they were once continuous across the intervening space C. This space then is due to the erosive action which has removed the upper beds, and denuded or laid bare the lower bed No. 4, across the valley C, and for an indefinite distance on the other side of the hill B. We should feel quite certain that not only the beds 1, 2, 3, 4, but also 5, 6, 7, etc., had stretched across this space formerly, and had also extended beyond the hill B for some indefinite distance in the direction of D. This latter conclusion we should in many cases find confirmed by the occurrence, at a distance perhaps of many miles beyond B, in the direction D, of a locality where the beds dipping in an opposite direction from that in fig. 73, these very same beds (1 to 8 of fig. 73) are brought in again in the very same order and with exactly the same character as before. (See fig. 74.) In some cases, such a little isolated basin forms the only remaining patch of the beds left in this new district, the disturbing action having there caused them to dip down below the level of the surface which has been formed by the denuding agent, and remain as a monument of their former extension over the wide intervening space between this new locality and that of the escarpment and outlier before mentioned.*

Fig. 74.
Outlying basin.

Geological maps of large countries often enable us to prove by such reasoning as this the former extension of a great mass of beds over very wide areas, and consequently the very large amount of denudation that has taken place.

Instances of denudation in the south of Ireland.—In the south of Ireland, for instance, several large detached areas of the rocks known as the Coal-measures occur resting in hollows formed by the upper beds of the formation known as the Carboniferous limestone. These Coal-measure beds usually end in an escarpment overlooking lower ground formed by the limestone, as at A in fig. 75.

The escarpments in these widely separated tracts of Coal-measures are so similar, and the beds composing them so precisely alike, that it is impossible to suppose otherwise than that they originally formed

* For some striking details on the subject of denudation, see Professor Ramsay's paper on the Denudation of South Wales, etc., in Memoirs of the Geological Survey of Great Britain, vol. i.

continuous sheets of rock, although they are now separated by sixty or eighty miles of ground composed of undulating beds of rock that lie below the Coal-measures. This belief is strongly confirmed by the fact, that there are often, between the two larger areas, several little outlying

Fig. 75.

Escarpment of Irish Coal measures overlooking plain of Carboniferous limestone.

patches in which the Coal-measures are found capping the summits of small hills, as at B in fig. 75, and that wherever the undulation of the limestone is such as to bring its upper beds down beneath the level of the present surface of the ground, we invariably find some of the lower beds of the Coal-measures coming in upon them.

The Slievenamuck Fault.—At one of these intermediate points there is a great fault with a downthrow to the north of not less than 4000 feet, as shewn in fig. 76.

Fig. 76.

Section shewing the Slievenamuck fault near Tipperary.

Cm. Coal-measures. O. R. S. Old Red Sandstone.
C. L. Carboniferous Limestone. S. Silurian Rocks.

The Coal-measures here are about 800 feet thick, and rest on Carboniferous limestone, of which numerous beds crop out towards the north, making a total thickness apparently of not much less than 3000 feet.

From underneath this limestone certain beds of sandstone, called Old Red Sandstone, crop to the north, forming a low hill, which may be called the Emly Ridge. The thickness of this Old Red Sandstone is not there determinable.

In the country to the south, however, we get the same Carboniferous limestone in the vale of Aherlow, with the same Old Red Sandstone rising from underneath it, and forming a hill called Slievenamuck, 1200 feet high. In this hill its beds are well seen, nearly from top to bottom, and their total thickness cannot be less than 1000 feet. Moreover, on the northern slope of this hill, the bottom beds of the Old Red Sandstone are exposed, and may be observed to rest on the uptilted and previously denuded edges of certain slates and grits which are of much greater geological age, and probably belong to the formation

known as Lower Silurian, and some depth of these are shewn on the face of the hill. But on descending the hill, a little lower, we come suddenly on to the Coal-measures dipping at a gentle angle to the south, and abutting directly against the Lower Silurian rocks, shewing a down-throw to the N. equal to the whole amount of the thickness of the rocks above mentioned, namely, 1000 feet of Old Red Sandstone; 3000 feet of Carboniferous Limestone, and 800 feet of Coal-measures, or taking a minimum 4000 feet.—(See Sheet 6 of the Horizontal Sections, and Explanation of Sheet 154 of the Maps of the Geol. Survey of Ireland by Mr. J. O'Kelly).

This section, when examined in connection with the surrounding district, is a very instructive one. We may learn from it—

1st. That the rocks called Lower Silurian were greatly disturbed and denuded so as to have a surface formed across the edges of their beds before any other rock was deposited upon them.

2dly. That upon the surface so formed the series of sandstones called the Old Red Sandstone were deposited horizontally, and without any disturbance, and that the whole of the Carboniferous limestone and the Coal-measures were similarly accumulated over the Old Red Sandstone in regular unbroken order, by parallel or "conformable" deposition, so as to make a thickness of horizontal beds at least equal to 4000 feet.

3dly. We learn that subsequently to the deposition of the last of these beds disturbance took place, the rocks were lifted up, tilted and broken through, and that dislocation took place to the amount just stated.

4thly. At the time that this dislocation took place the Coal-measures must certainly have existed generally over the surface, or the dislocation could not have brought down beds belonging to them—a conclusion confirmed by the occurrence of other isolated patches of Coal-measures still existing all round the district at the distance of a few miles from this spot.

5th. Since the disturbance of the country, denudation has removed all the Coal-measures from off the district except the patches mentioned above, and, moreover, has removed large portions of the upper part of the Carboniferous limestone, since the lower beds of that formation now appear at the surface in the greater part of the neighbourhood. But it has done more than that, for in those spots where the Old Red Sandstone now forms the surface rock, not only the whole of the Coal-measures, but the whole of the limestone must have been removed, and, moreover, it has cut deeply into the Old Red Sandstone, and in some places right through even that, and swept it clear away, so as to re-expose the old denuded surface of the Lower Silurian rocks, on which the Old Red Sandstone was deposited, and has even gone yet further

still, for this more recent denudation has in some adjacent localities, especially along the northern slope of the Galty mountains, which lie south of the vale of Aherlow, eaten down so as to wear deep hollows and valleys into the Lower Silurian rocks themselves, several hundred feet below that surface on which the Old Red Sandstone was deposited.

General Structure of the South of Ireland.—But the conclusions deduced from the examination of the structure of this part of Tipperary may be extended to the whole of Ireland, over the greater part of which the above-named formations are to be found undulating above and below the present surface of the ground, the Coal-measures coming in generally as high land resting in a basin of the Carboniferous limestone as at B, fig. 75, and the Old Red Sandstone and Silurian rocks rising out from underneath the limestone often into hills still loftier than the highest parts of the Coal-measures, and commonly causing great anticlinal curves in the Old Red Sandstone.

The Commeraghs, the Knockmealdowns, the Galtees, the Slievebloom, the Keeper group, and the higher mountains of Kerry and Cork generally, all come within the latter class.

Fig. 77 is a diagrammatic section running from W. to E. across the "Devil's Bit range," a part of the Keeper group where the original

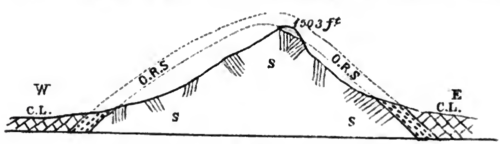


Fig. 77.

Diagrammatic section across the Devil's Bit Mountain.

C.L. Carboniferous Limestone.

O.R.S. Old Red Sandstone, its denuded part being shewn by the dotted lines.

S. Lower Silurian rocks.

anticlinal form of the Old Red Sandstone is proved by a small capping of it left on the summit of the hill.*

Farther south and south-west of this point the Old Red Sandstone is much thicker, and has not therefore been so often worn through and removed by the denudation as in the Keeper and Galty groups. Figs. 75, 76, and 77 will give a good general notion of the structure of most of the hills of Ireland.

This description may be extended also to Scotland, and to large parts of England and the Continent, and, indeed, to every country in the world so far as the principles are concerned, and making allowance for

* See Mr. A. B. Wynnes' description of this district in the Explanations of Sheets 135 and 145 of the Geol. Survey of Ireland.

differences in the formations and in the positions into which they are thrown.

Plains caused by Denudation.—It has been already said that the very plains and low lands themselves are in some cases the result of denudation, whole mountains of rock having been removed from them. The central plain of Ireland gives us an excellent example of this principle also, as the rocks below it consist chiefly of beds of the lower part of the Carboniferous limestone, from which the Coal-measures and

Fig. 78.

Representing general structure of central plains of Ireland, formed of undulating beds of the lower part of the Carboniferous limestone, covered here and there with limestone gravel.

upper parts of the limestone have been removed; a general thickness of 2000 or 3000 feet at least, perhaps even 5000 or 6000 feet of rock being thus lost. It is the case also with the low lands of Wexford and other parts of Ireland, in which highly inclined, often vertical, beds of Lower Silurian, and even of still lower Cambrian rocks, are found just beneath the surface.

This is true, also, of Anglesea, and the lower parts of Caernarvonshire, which have a surface made across the eroded ends of uptilted Cambrian and Lower Silurian beds, that were undoubtedly once buried deep beneath the higher beds that form the summits of the hills of the Snowdon range.

It is remarkable that, in Wales, it is in Anglesea only, where the denudation seems to have cut deepest, that we meet with granite, and that in Leinster, where we have the largest exposure of granite in the British Islands, the denudation can be shewn to have been enormous, but we will defer the discussion of this part of the subject till we come to examine the petrological relations of granite. It is sufficient for our present purpose to shew that many low lands are low because mountains of rock have been removed in order to form their present surface.

Inconceivable time required for action of Denuding forces.—The only agent to which we can reasonably attribute the destruction and removal of masses of rock, notwithstanding that they were many thousands of feet in thickness, and many hundred thousand square miles in extent, is the slow and gradual gnawing of the sea breakers upon coasts, an action always tending to plane down land to a little below the level of the upper surface of the ocean.

The time required for such a slow process to effect such enormous results, must of course be taken to be inconceivably great. The word "inconceivably" is not used here in a vague but in a literal sense, to indicate that the lapse of time required for the denudation that has produced the present surfaces of some of the older rocks is vast beyond any idea of time which the human mind is capable of conceiving.

Mr. Darwin in his admirably reasoned book on the origin of species, so full of information and suggestion on all geological subjects, estimates the time required for the denudation of the rocks of the Weald of Kent, or the erosion of the space between the ranges of chalk hills known as the North and South Downs, at three hundred millions of years. The grounds for forming this estimate are of course of the vaguest description. It may be possible, perhaps, that the estimate is a hundred times too great, and that the real time elapsed did not exceed three million years; but, on the other hand, it is just as likely that the time which actually elapsed since the first commencement of the erosion till it was nearly as complete as it now is, was really a hundred times greater than his estimate, or thirty thousand millions of years.*

The only object we can have in mentioning such numbers, is to make more clear what it is we mean, when speaking of the lapse of geological time. It is not till we have raised our notions of geological time up to the height of believing that we have recorded in the crust of the earth the lapse of many periods, each consisting of many thousands of millions of years, that we are able to conceive the possibility of agents such as we see now at work on the earth producing the great effects which have been produced.

Atmospheric Denudation as shewn in the valley of Moselle and other rivers.—The allowance of these vast spaces of time enables us to understand also another variety in the action of denudation, that, namely, exercised by rivers running upon dry land.

The valley of the Moselle river, and the ravines of its northern tributaries in the country of the lower Eifel, give us an admirable instance of this river denudation, as I convinced myself during a short excursion through that region in the summer of 1859.† That country is composed of highly and variously inclined palæozoic rocks, probably of some Silurian age. Its general surface forms a gently undulating land about 1000 or 1200 feet above the level of the sea. This country is dotted over with a great number of the most curiously

* The bare counting of thirty thousand millions at a rate of sixty in a minute for every hour in the twenty four, would occupy 950 years; since the number of seconds in 365 days is only thirty one and a half millions.

† Professor Ramsay, whom I joined at Bertrich on that occasion, and under whose guidance I spent a few days in examining the country, had arrived at the same conviction. It was almost the first subject of conversation between us on meeting, and we found our opinions, independently formed, in perfect agreement on the point.

minute volcanic cones and craters to be found, I should think, anywhere in the world.*

It is also furrowed by numerous narrow ravines with steep, sometimes precipitous sides, which cut down, as they near the Moselle, to depths of 600 or 800 feet below the general surface of the country, and wind through it with the most sinuous curves imaginable. The Moselle itself works its way through the district by an equally tortuous course, forming loops that after a bend of some miles often cut back so as to leave but a narrow ridge between some parts of the ever-curving reaches of the river. This singularly winding valley is both narrow and deep, being closely environed on all sides by steep precipitous banks, 800 or 1000 feet in height, with frequently no more room between their opposing bases than just sufficient for the river itself.

It is clear that such deep winding channels in hard rock could not have been excavated by the waters of the sea, or by any other conceivable action than that of water running in lines over dry land, and deflected hither and thither according as it was turned aside by meeting with obstacles or induced by facilities to its passage—in other words, by rivers.

The shapes of the curves are exactly like those made by a river traversing an alluvial flat.

Fig. 79 will serve to explain the difference between the wide-spread

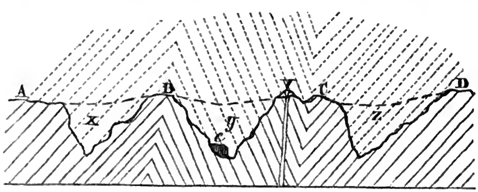


Fig. 79.

probably marine denudation, by which the general surface of the country, A, B, C, D, has been produced, in consequence of the removal of the rock marked by the dotted lines, and the local river action which has cut down below that surface so as to form the ravines x, y, z. The letters v, e, refer to the volcanic rocks ; and it is obvious from the patches of lava now found in the bottom of the valleys that those excavations were very much in their present state when the volcanic erup-

* The volcanoes near Bertrich, such as the Falkenlei and the Facherhue, are really pocket editions, almost cabinet specimens, of volcanoes, the cones not exceeding fifty feet in height, or a hundred yards in diameter at the base.

tions took place, although the craters burst out on the higher land—a circumstance which makes it probable that the depth of the valleys is infinitessimally small compared with that of the source of the volcanic action.

The far larger, or at least much wider valleys excavated through the soft tertiary rocks of the Auvergne country have been similarly the result of river and weather denudation, as is shewn, not so much by their form, as by the relation to them of the various and successive streams of lava from the neighbouring volcanoes and the river channels which have cut through the lava streams, as well as by the absence of any marine "drift" and the presence of fresh-water gravel and other deposits proving the absence of the sea.—(See *Scrope's Volcanoes of Central France*, chap. ix.)

I believe that many of the river valleys of our own islands have, in like manner, been excavated by the rivers themselves to a much greater extent than we have been in the habit of supposing.

Different periods of Denuding Action.—In examining the denudation that has affected the older rocks, it is necessary to be on our guard against attributing the whole of it to any one period, and especially to the last period during which denudation has been active on the country.

Our present land surfaces are, in almost all cases, the result of many periods of action, both marine and atmospheric—those periods having been often separated by great intervals of time.

With respect to the surfaces on the older rocks, it is often easy to shew that the principal action of denudation that affected them took place at a very early geological period, and that our present surfaces are either themselves very old surfaces geologically, or that at least they differ from a very old surface much less than that differed from the original surface of deposition that existed immediately after the formation of the rocks.

On turning to figs. 76 and 77, for instance, we see that the base of the Old Red Sandstone in Slieve-na-muck rests upon an old surface that was formed across the edges of the beds of the Lower Silurian formation during some time antecedent to the formation of the Old Red Sandstone, which was deposited upon these denuded edges.

This peculiarity of position is called unconformability, which it is necessary we should examine in order to rightly understand the evidence in support of the different periods of denudation and different ages of land surface.

CHAPTER XVI.

UNCONFORMABILITY AND OVERLAP.

Unconformability arises from a surface of Denudation having been formed in one set of Beds before the Deposition of another set.—When one group of beds rests upon the denuded edges of another group, the upper is said to be unconformable to the lower group. In most cases the lower group will have been tilted before the edges of its beds were denuded, and the upper group will be deposited upon those uptilted and denuded edges, so that there will be a marked difference in the "lie" of the two sets of rocks. It has resulted from this that the commonly received idea of unconformability refers rather to this difference in their "lie" than to the fact of the intermediate period of denudation.

The following is the most general statement of what constitutes "unconformability:"—*When the base of one set of beds rests in different places on different parts of another set of beds, the two are unconformable to each other.*

For unconformability to arise, then, there must be two different sets or groups of beds which had an interval, more or less great, between their periods of production, that interval being unrepresented by any deposition in the place where the unconformity exists, though it must be marked by a more or less obvious denudation.

Overlap, on the other hand, takes place only in the same set of beds, or in different sets of the same conformable series.

In fig. 80 we have represented one of the simplest cases of uncon-

Fig. 80.
Simple unconformability.

formability in which the lower groups of beds *m m* have been uptilted and denuded, so as to form the horizontal surface A B, on which the beds X X have been deposited.

Instances are not wanting, however, in which the lower set of beds have had their edges denuded without being tilted from the horizontal, or at all events having so close an approximation to horizontality at the time of the deposition of the superincumbent beds, that no sensible difference is now to be detected in the "lie" of the two groups in the places where they are exposed. Fig. 81 will serve to explain this case, in

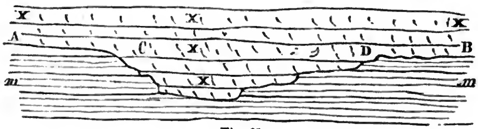


Fig. 81.

which the beds *m m* still remaining horizontal have had their surface A B worn in some places into hollows and cliffs, in or against which the beds X X have been deposited. If these two sets of beds chance to be exposed in places where the surface A B happened to be horizontal at the time of the deposition of X X, as in the parts between A C or D B, their unconformability may not be at first perceived.

An example of this case may be found in the South Staffordshire coalfield, where the beds X X are represented by the Coal-measures, and the beds *m m* by the Silurian rocks.—(See *Mem. of Geol. Survey*, Geology of S. Staff. Coalfield, 2d edition, p. 80.) In true unconformability, then, the lower group has always had a new surface formed across the edges of the beds, that surface being somewhere an inclined one if the beds are horizontal, while, if the beds are inclined, the surface may be horizontal, or may cut across their edges at any angle or in any direction.

A paper on the Shropshire Coalfield was recently read before the Geological Society of London by Mr. Scott, from which it appeared that the upper part of the Coal-measures was there unconformable to the lower part. If this was a case of real unconformability, it is probable that it was of a purely local kind, and rather, perhaps, an extension of what has previously been described as "contemporaneous erosion and filling up" (see p. 193), which is doubtless a minor and purely local kind of unconformability. This, however, as it takes place merely in a smaller portion of one group of rocks, is not to be confounded with the unconformability that exists between two groups.

Successive Unconformabilities in South of Ireland.—Very complicated cases of unconformability are to be found in some places, especially among the older rocks. In the south of Ireland, for instance, there are cases in which the Lower Silurian beds rest unconformably on the upturned and denuded edges of the older Cambrian rocks, while they

present a completely discordant surface themselves for the reception of the lower beds of the Carboniferous formation, which likewise not only rest unconformably on the Lower Silurian beds, but are themselves often greatly disturbed and denuded. So that we have, within a small area, proofs of three several periods of elevation and denudation having taken place, each period of elevation having gone the extreme length of placing the rocks in some parts into the vertical position, and each period of denudation having formed a surface across the edges of the uptilted beds before the next deposition took place upon them.

Fig. 82 is a section near Ashford, in county Wicklow, shewing the

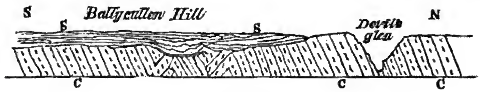


Fig. 82.
Section from south to north across the Devil's Glen and Ballycullen Hill, near Ashford, County Wicklow.

unconformability of the Lower Silurian, marked S S, on the Cambrian beds marked C C.

Fig. 83 is one of almost innumerable sketches that might be given in which the unconformability of the Old Red Sandstone to the Lower

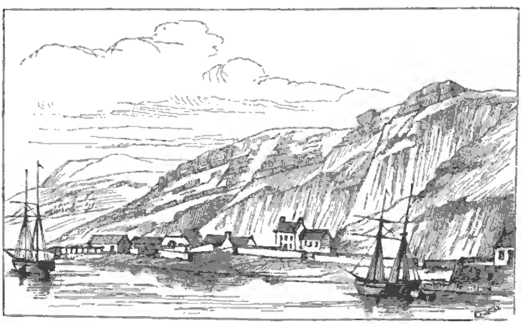


Fig. 83.
Sketch of the cliffs on the north side of the River Suir, opposite the town of Waterford.

Silurian is plainly observable. It is from a sketch by Mr. Du Noyer of the cliffs opposite the town of Waterford, in which the Old Red Sandstone may be seen forming slightly inclined beds that cap the hills, and

rest upon the edges of highly inclined, nearly vertical, beds of green and blue slate belonging to the Lower Silurian period.

The Carboniferous limestone of the south of Ireland is always conformable to the Old Red Sandstone below, although it often overlaps it, in consequence of the comparatively small area within which the Old Red Sandstone was deposited, the Carboniferous Limestone being much more widely extended. In one place near Taghmon, county Wexford, a patch of the Carboniferous Limestone was found resting directly on the Cambrian rocks, and at a distance of nine miles from the remainder of the Carboniferous Limestone, shewing that the Cambrian had there been denuded of the whole of its former covering of Lower Silurian, and the Carboniferous Limestone spreading beyond the limits of the Old Red Sandstone, rested directly on the Cambrian.

A similar occurrence is known near Corwen in North Wales, where an isolated patch of Carboniferous Limestone rests on the lower part of the Upper Silurian rocks, at a distance of ten miles from the main mass of the Carboniferous Limestone, which now ends in an abrupt escarpment, 600 feet in height, just north of Llangollen.

These two cases are proofs also of the subsequent denudation of the Carboniferous Limestone itself, since we must believe that the now separated portions formed originally parts of a continuous mass of limestone that covered the whole surrounding country.—(*See sheets* 74 *N.W. and* 74 *N.E. of the Geological Maps of England and Wales, and sheet* 169 *of Ireland.*)

In the south of Ireland we may follow the boundary of the Carboniferous Limestone and Old Red Sandstone through the counties of Kilkenny and Carlow, so as to find the most convincing proof of the denudation of the Lower Silurian rocks, even to the extent of laying bare the granite which lay beneath them, before the deposition of the Old Red, and of the

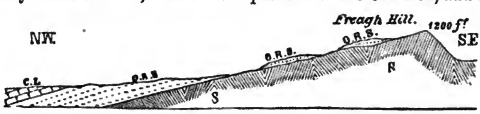


Fig. 84.

Section from N.W. to S.E. over Freagh Hill, 1200 feet high.
S. Lower Silurian.
O. R. S. Old Red Sandstone.
C. L. Carboniferous Limestone.

subsequent overlap of the Carboniferous Limestone, and its deposition on the bare granite without the intervention of any other formation.*

* It is necessary, in order to explain fully the subject we are describing, to take for granted that the student knows what the Carboniferous Limestone and Old Red Sandstone are. He may either refer to their description as given further on, or return to this chapter at a future period.

Fig. 84 is a diagrammatic section taken across Freagh Hill, a few miles north of Thomastown, in the county of Kilkenny. The Lower Silurian rocks, marked S S, were disturbed and contorted, and a level surface formed across their edges, on which the Old Red Sandstone was deposited uncomformably, with the Carboniferous Limestone conformably upon it. Subsequent elevation and denudation has removed all the Carboniferous Limestone from all the high ground, and also the Old Red Sandstone, except one or two patches of it, re-exposing in places the old level floor or surface of Lower Silurian on which it was deposited. But it has even gone beyond that, for the valley at the south-east end of the section has probably been excavated in the Lower Silurian by the subsequent denudation, and did not exist at the time the Old Red Sandstone was deposited, otherwise it would have been filled with it, and some part, at least, of it would now remain there.

Fig. 85 is a diagrammatic section taken a few miles south of Thomastown, where the denudation that had acted previously to the

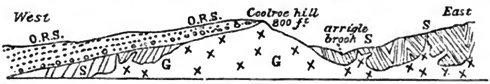


Fig. 85.

Section from west to east through Coolroe hill, and across the Arrigle brook, near Glenpipe.

G. Granite.
S. Lower Silurian.
O. R. S. Old Red Sandstone.

deposition of the Old Red Sandstone had laid bare a portion of granite, the last outlying piece of granite of the great granite band of Leinster. The Lower Silurian rocks are traversed by granite veins in the neighbourhood, and are, near the granite, altered into mica schist, and their beds are highly inclined. The Old Red Sandstone, on the other hand, rests upon the granite quite undisturbedly ; it is quite unaltered by the granite, and is obviously made chiefly of the sand derived from the waste of the granite, containing occasionally even pebbles of the granite, though not so many pieces of granite as it does fragments of the slate rocks, when it rests upon them. The granite is now readily decomposed and easily crumbles into sand, and did so apparently quite as easily at the time the Old Red Sandstone was deposited upon it.

There is here, too, every appearance of a nearly level floor having been formed upon both Lower Silurian and granite for the reception of the Old Red Sandstone, and proof of the subsequent denudation having removed the extension of the Old Red Sandstone, and worn hollows beneath that floor down into the subjacent rocks.

Fig. 86 is a diagrammatic section representing the "lie" of the rocks in county Carlow, about 15 miles north of Thomastown, where

granite and Carboniferous Limestone lie side by side, making low gently undulating ground, largely covered with limestone gravel, which has been omitted in the diagram. The limestone dips gently from the granite, but is quite unaltered by it, is not traversed by any veins from

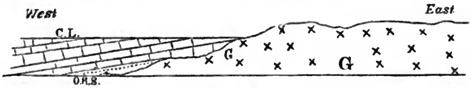


Fig. 86.

Section from west to east in county Carlow.

G. Granite.

O. R. S. Old Red Sandstone.

C. L. Carboniferous Limestone.

it, and was evidently deposited in the sea upon a bare floor of granite, just in the same way that beds might now be deposited upon the bare granite if it were again depressed beneath the sea, or as the limestone gravel was deposited on it at the last period of submergence. No Old Red Sandstone appears here from beneath the Carboniferous Limestone, as it gradually thins out and disappears as we proceed north from Thomastown. As, however, it does appear again a few miles to the westward, some has been introduced into the diagram (fig. 84) to suggest the probable mode of its occurrence in that direction.

That the limestone was deposited upon the previously existing and previously denuded granite is proved by what takes place still farther north in county Dublin, where angular fragments of granite are found included in the limestone, as will be described presently.

Denudation involves existence of Dry Land, Unconformability that of subsequent Depression.—From what has now been said on denudation and unconformability it will be plain that denudation, or the production of a new surface on rock, can only take place as a consequence of the elevation of the rock up to or above the sea level, and seems, therefore, to involve the necessity of the appearance of dry land, in some part, at least, of the area which is affected by the denudation. Unconformability, or the deposition of fresh beds upon a denuded surface, of course necessitates the depression of that surface below the water, in which alone these aqueous rocks can be formed.

The occurrence of this discordance, then, between the upper surface of one set of beds and the lower surface of another, may in itself be taken as a proof of elevation, denudation, and subsequent depression having occurred, and as a presumptive evidence of dry land having existed in the neighbourhood at some time during the interval which elapsed between the formation of the two sets of beds.

The probable existence of dry land is often confirmed independently, as in the case of the granite sand and fragments scattered in the Car-

boniferous limestone of Dublin; the most probable cause for their occurrence being their transport in the roots of plants, which grew somewhere on the granite land, and were washed down into the Carboniferous sea.

Such an apparently uninteresting circumstance as the relative lie and position of two sets of rock thus gives us, when it is properly studied, a curious and unexpected history.

Practical importance of the subject.—Unconformability, however, has its practical as well as its speculative interest, since it is necessary that it should be thoroughly understood in all searches for materials belonging to one group of beds carried on through beds belonging to another set.

In the north of Ireland a strong feeling exists in favour of sinking through the New Red Sandstone of county Antrim and its borders, in search of coal; that feeling being based on the knowledge that the New Red lies above the Coal-measures. Since, however, it lies *unconformably* upon them, it follows that though in one district it may rest upon Coal-measures, in others it may lie upon any other formation which comes out from underneath the Coal-measures, and from the structure of the neighbourhood it appears that the chances are something like twenty to one against the Coal-measures being found under any particular spot of the New Red Sandstone.

I have myself known money uselessly thrown away in sinking shafts in the South Staffordshire coal-field for want of attention to the slight unconformability of the Coal-measures on the Silurian rocks. In future explorations, such as at no great distance of time will be undertaken, in search of coal in the central districts of England, the clear and complete comprehension of this subject will be of the highest practical importance, and indeed absolutely necessary to avoid the fruitless expenditure of great sums of money. Many hundreds and many thousands of pounds have been thrown away, even during the last few years in the central parts of England alone, in abortive mining attempts after coal, the expenditure of which nothing but the most complete ignorance of geology could have rendered possible. The detailed maps lately published by the Geological Survey of the United Kingdom would make such ridiculous attempts still more inexcusable for the future, but it is possible that even those very maps might lead to error, unless they be thoroughly understood and soundly interpreted, with every allowance for unconformability and similar petrological structures.

Overlap.—Overlap has been already said to occur only in the same set of beds, or in the same conformable series. It may be described as the extension of one bed, or set of beds, beyond the original termination of the bed or set of beds below it.

The lower bed, or set of beds, may not have been at all denuded, or in any way changed from their original lie and position, neither is it necessary that any unusual interval should have elapsed between the production of the lower beds and those that overlap them. The simplest case of overlap indeed must always occur wherever any bed originally terminated, since the next bed would rest partly upon that bed, and partly upon the one below it.

This form of overlap must then be of general or even universal occurrence among stratified rocks, and need not be more particularly described than it has been already, when speaking of the "extent and termination of beds" at p. 183. It is the same minor and local form of overlap that contemporaneous erosion and filling up is of unconformability. True "overlap," however, is of more importance, since it occurs, not merely with respect to new beds or small sets of beds, but among large groups in a conformable series, which overlap each other successively, in consequence of the newer groups spreading over wider and wider areas than those below them.

Instances of this form of overlap occur with respect to the groups called Old Red Sandstone, and Carboniferous Limestone in many parts, both of England and Ireland. The two formations are always conformable to each other wherever they occur together, but while the lower one, the Old Red Sandstone, is in some places many hundreds (or even thousands) of feet thick, in others it shews merely a few beds, and in others does not occur at all, so that the Carboniferous Limestone must necessarily, where the Old Red Sandstone is absent, rest upon Silurian or other lower rocks. In like manner the Coal-measures in some parts overlap the Carboniferous Limestone, and rest upon lower rocks.

Similar "overlap" seems to take place in England between the different members of the Oolitic series, and with respect to the upper Cretaceous and Wealden groups, though it is not improbable that in some of these instances it becomes actual unconformability, in other words, that the lower group had been more or less worn, and a new surface formed on it by denudation before the upper was deposited.

The Geological Structure of the county Dublin.—It is sometimes very necessary to take notice of the overlap of groups of beds in order to form a right notion of the structure of certain districts.

An instance of this occurs in the county Dublin, which it is worth our while to describe, as it gives us an excellent example of the combined results of denudation, unconformability and overlap.

We have in this district the following groups of rocks :—

AQUEOUS ROCKS.

Upper Palæozoic.
- Coal-measures.
- Carboniferous Limestone.
- The Lower Limestone shale.
- Old Red Sandstone.

Lower Palæozoic.
- Lower Silurian Rocks.
- The same altered into Mica Schist.
- Cambrian Rocks.

IGNEOUS ROCKS.

Granite.

There are also certain greenstones and other igneous rocks associated with the Cambrian and Lower Silurian rocks, as dykes, veins, or small bedded masses, but these need not be noticed here.

The southern part of the district is formed of hilly, quasi-mountainous ground, composed of granite with the Lower Silurian rocks on each side of it. These Lower Silurian rocks pass into mica schist with layers of semicrystalline staurolite or andalusite as they approach the granite. The high land of the promontory of Howth is composed of highly contorted Cambrian rocks, with Carboniferous Limestone abutting directly against them on the land side. Lambay Island, and the coast near Portraine, and also the ground about Skerries, and some distance to the north of it, is formed of the Lower Silurian rocks.

On the land side of Portraine, Old Red Sandstone is found with a thickness of some 300 or 400 feet, as may be seen in the railway cutting near Donabate. This Old Red Sandstone is overlaid conformably by beds of black shale forming the base of the Carboniferous series, and spoken of as the lower Limestone shale, and the remainder of the district consists of low land, beneath which are found the tilted and often violently contorted beds of Carboniferous Limestone (see fig. 31), except in one or two places where that limestone dips underneath beds of black shale which are the base of the Coal-measure series. Those shales generally form low rounded hills, rising 100 or 200 feet above the level of the denuded surface of the limestone (see fig. 87, map).

At Crumlin, three miles west-south-west of Dublin, and at two or three other places in that neighbourhood, angular fragments of granite and mica schist, and layers of granite sand, have been found in the limestone. Similarly, on the shore near Rush, and farther north towards Skerries, the Carboniferous Limestone contains large blocks of Lower Silurian trap rocks and gritstones, as well as smaller angular and rounded fragments of those rocks, and of green and gray slate,

down to fine debris of the adjacent Lower Silurian rocks, sometimes to such an extent, that one or two beds in the limestone resemble the Lower Silurian rocks of Lambay, Portraine or Skerries, rather than a bed of Carboniferous Limestone. Similar beds recur in the

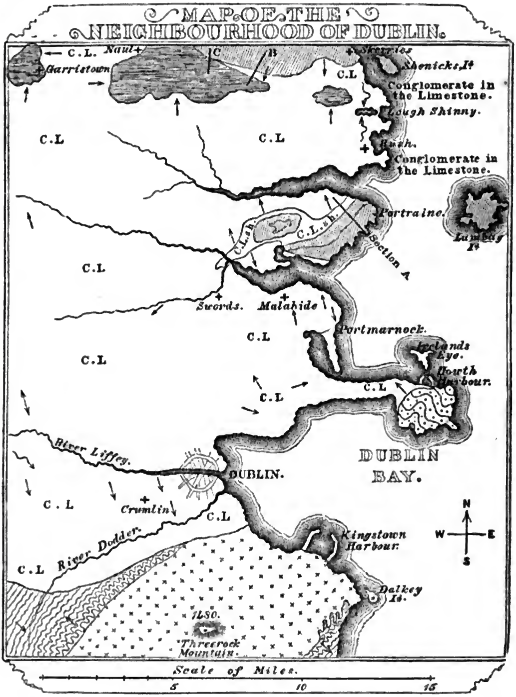


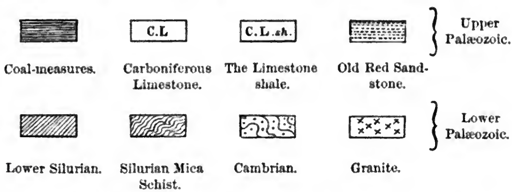
Fig. 87.

Fig. 87 is a rough reduction of sheets 102 and 112 of the Geological Survey of Ireland.

country a few miles west of Swords, where however, they are imperfectly seen, and are not noticed in the map (fig. 87).

The first thing that strikes us in looking at the map of the district

is that the Upper Palæozoic rocks, taken as a whole, rest in different places on different parts of the Lower Palæozoic rocks, and upon the granite. The upper therefore are completely unconformable to the lower. The Lower Palæozoic rocks and granite now lying beneath the Carboniferous Limestone must have a precisely similar surface beneath it, to that



The Coal-measures are marked by horizontal lines, and are found only in the northern part of the district, the small patch at Lough Shinny ought to have been extended out to the shore there ; as engraved it looks as if it were intended for a lake. The Old Red Sandstone is represented by dots, which are however much smaller, in the map than in the descriptive labels.

The granite has been included among the Lower Palæozoic series here, because the Leinster granite was certainly injected into the Lower Silurian rocks before the termination of the Lower Palæozoic period.

which they have where they rise out from under it. The denudation of the Lower Palæozoic, therefore, which had taken place previously to the Upper Palæozoic period, must have been enormous, and the present surface of the ground in the Lower Palæozoic part of the country was nearly, and in some places quite arrived at during that early geological time. Any denudation at all events that has happened to the Lower Palæozoic rocks since the time of the deposition of the Carboniferous Limestone must be insignificant compared with that which had been completed before that time.

Although there is not in the district, then, any good section shewing the junction of the Upper Palæozoic rocks with those below them, the mere inspection of the country, or of the map, completely establishes the fact of this previous denudation, and wide unconformability.

The fragments of granite embedded in the limestone at Crumlin and other places, also prove that the granite was at the surface before the Carboniferous period.

The next thing that would strike us is, that although there are so many miles of boundary to the Upper Palæozoic rocks, yet the Old Red Sandstone and lower Limestone shale only appear at one part, and that near the centre of the district. Along both the southern and northern boundaries of the Upper Palæozoic country, there is no appearance of the base of the Upper Palæozoic rocks; not

only so, but judging from the dip of the rocks, marked by arrows in the map, it appears as if the upper beds dipped towards the southern boundary, and therefore, that we had there an upper instead of the lowest part of the series. This was for a long time an inexplicable phenomenon to me when examining the country, until I visited the neighbourhood of a place called "Naul," near the northern margin of the district, in company with Mr. Du Noyer. It then immediately struck me that certain beds of black shale just south of that place, belonged in reality to the Coal-measures, a conclusion since amply confirmed by Mr. Baily, when he examined the fossils.* It was then clear that in this neighbourhood we had the uppermost beds of all close to the boundary, and even in some parts resting directly on the adjacent Lower Silurian rocks, while the lowest beds of the Upper Palæozoic series existed only in the centre of the district.

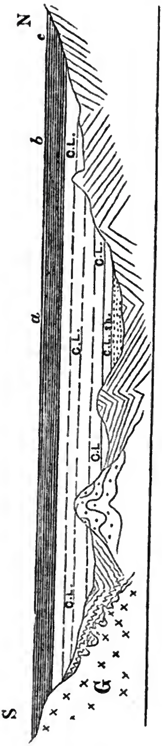


Fig. 88.

Representing the old Lower Palæozoic land buried under continually overlapping Upper Palæozoic beds.

The same characters are used to denote the rocks as in fig. 87.

These facts I at once perceived were explicable only on the principle of "overlap," in the following way :—

The whole district must have been dry land, formed of Lower Palæozoic rocks, with a widely denuded surface, as before explained. This dry land became subject to depression in the early part of the Upper Palæozoic period. The part about Portaine was either lower than the parts south of Dublin and west of Skerries, or was depressed more rapidly than them, so as to be the first part which was brought below the level of the water. Certain beds of sand, now forming the Old Red Sandstone of that locality, were accumulated there, and certain beds of black shale, forming the lower Limestone shale, were deposited over them as the depression continued. These beds did not extend far to the north or south of that locality, simply because the water ended against the shore, within a

* Mr. J. Kelly had previously published his opinion that these beds south of Naul were Coal-measures, but they had not been marked as such on any published map till that time.

short distance of it. As the land, however, continued to sink, the water extended further and further over it, and the beds deposited in that water acquired in like manner a wider and wider extension, and altogether overlapped those beneath them, as suggested in fig. 88.

It is probable that, as a final result, horizontal beds of Coal-measures spread over the whole area, resting upon the granite of the Dublin and Wicklow Mountains on the south, and on the Lower Silurian hills of Meath on the north, and completely concealing all the limestone below.

The subsequent actions of disturbance, of elevation with its concomitant tilting, contortion, and fracture, and the subsequent denudation resulting from the rocks being lifted up through the sea level, brought to light the lower limestones and sandstones in different places, according to circumstances, and re-exposed parts of the Lower Palæozoic rocks that had been covered.

At different places where these Lower Palæozoic rocks are now re-exposed at the surface, we find them passing under different members of the Upper Palæozoic series. At Portaine (*see section, fig.* 89, *a*), we find the Lower Silurian rocks covered by the Old Red Sandstone and the Limestone shale, as well as by the Carboniferous Limestone above them. We may suppose that we have here the part beneath the letter *a*, in fig. 88, brought up to the surface.

Fig. 89, *a*.
Section at line A in fig. 87.

At another place we should have the "lie and position" of the rocks, as shewn in fig. 89 *b*, which is taken between two little places called the Man of War, and the Cross of the Cage, three or four miles west of Skerries. Here, there appears neither the Old Red Sandstone, nor the Limestone shale, but merely a portion of the Carboniferous Limestone resting unconformably on the Lower Silurian rocks, and covered conformably by the base of the Coal-measures. This would answer to the part beneath *b*, in fig. 88.

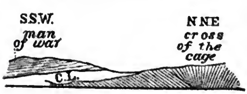


Fig. 89, *b*.
Section along line B in fig. 87.

Two miles further west again we have the section, as in fig. 89 *c*, taken at a place called Bog of the Ring along the line marked C in the map, where the Coal-measures seem to be in direct contact with the Lower Silurian rocks, resting of course unconformably upon them, but without the intervention of any of the lower members of the Upper Palæozoic series. This would be the exposure of the part beneath the letter *c* in fig. 88.

Fig. 89, *c*.
Section along line C in fig. 87.

The conglomerates consisting of fragments of Lower Silurian rocks, which are found in several parts of the Carboniferous Limestone, are probably derived from the waste of some isolated crags or peaks which remained for a time exposed to the action of the waves of the Carboniferous sea, and were finally destroyed by them, and the materials strewed around over the bed of the sea.

The granitic and metamorphic fragments in the limestone south of Dublin, may possibly have had a similar origin, or they may, as previously suggested, have adhered to the roots of trees that grew upon what are now the Dublin and Wicklow Mountains, and were swept down by floods into the adjacent sea.

The Hill of Howth clearly existed as an island with very much its present outline, so far as its base is concerned at all events, in the Carboniferous sea, and was certainly in part, probably altogether, enveloped and inclosed in beds of Carboniferous Limestone which were formed in that sea. Some of the old conglomerates formed on its surface may still be seen in Balscadden Bay, near Howth harbour.

The black shales which are frequent in the upper part of the Carboniferous Limestone, and which are still more abundant in the lower Coal-measures, which are indeed almost entirely composed of them, may probably be derived from the waste of a land of similar composition (Lower Silurian or other rock), to which the sea had now gained access in consequence of the continuance of the depression.

The whole circumstances of the gradual depression of the country during the formation of the Carboniferous rocks of Dublin and the neighbourhood might very well be repeated, *mutatis mutanda*, if the country were again slowly depressed, and a series of tranquilly deposited rocks were slowly and gradually formed upon it.

It is hoped that a careful perusal of the preceding descriptions will shew the importance, both practical and theoretical, of paying attention to the structures known as overlap and unconformability, and will also be sufficient to enable us to take for granted that overlap is in itself a proof of depression having taken place, while unconformability may be held, as already shewn, to involve the occurrence of elevation and denudation, the probable existence of dry land, and of subsequent depression.

CHAPTER XVII.

THE GRANITIC OR HYPOGENOUS ROCKS.

In the previous chapters devoted to that part of Geognosy which is here called Petrology, we have examined chiefly the petrological relations of the Aqueous Rocks. It now behoves us to examine those of the Igneous class.

The different kinds of igneous rocks have been described under the head of Lithology, and it was shewn that these differences partly depended on the difference of their chemical composition, and partly on the texture resulting from the physical circumstances—as pressure and rate of cooling—under which their consolidation took place. The Granitic rocks, or those which are most completely crystalline and most thoroughly saturated with silica, cooled slowly and under great pressure, that is to say, at some considerable depth in the interior of the crust of the globe.

The Volcanic rocks, on the other hand, were consolidated at the surface, while the intermediate and variable class which we have called Trappean, may have been solidified under various and intermediate conditions.

Fundamental Granite.—As a matter of fact, it has been found that in all parts of the globe, wherever the base of the aqueous rocks has been brought up to the surface and exposed to view, that base rests upon granitic rocks. By the "base of the aqueous rocks" is meant the lowest aqueous or sedimentary rocks known in the particular locality, *whatever may be their age*, whether they be some of the oldest known rocks, or whether they be of a much later date than those, and whether they retain their original characters unaltered, or have been metamorphosed into Mica Schist, Gneiss, or any similar rock.

It is by no means intended to assert that the converse of this is true, and that wherever Granite is found at the surface, there the lowest of all known rocks, or even the lowest rocks of that particular locality, will be found reposing on it. On the contrary, we shall see presently that Granite always comes *through* great masses of rock, without bringing them up along with it. But at every place where any rock does make its appearance at the surface *from underneath the lowest* of

the *stratified* rocks known in that locality, that rock is a granitic one, and wherever any large mass of Granite comes to the surface, we have no reason to believe that any other rock but Granite would be found underneath it. I do not here speak of any veins, or intrusive dykes or sheets of Granite, but of large, widely extended masses. In short, we have every reason to believe that if we pierced vertically downwards into the earth at any part of its surface whatever, we should eventually come either to Granite or to yet molten and unconsolidated rock, which on cooling would form Granite. Again, in many parts of the world, Granite is found occupying large areas of the surface ; and we have no reason to suppose that any other rock but Granite would be found under those surfaces, although, if we sank deep enough, we might perhaps come eventually to red-hot Granite, and ultimately to yet molten Granite. These facts and these opinions have naturally led many early geologists to the conclusion that the earth was a once molten globe of fiery matter, and that on cooling there was formed about it a primæval crust of Granite ; and they hence inferred that much of the Granite now to be found at or near the surface was actually part of this primæval crust. At one time, indeed, it was held that all Granite had this primæval character ; but this notion has long been exploded, since *intrusive*, and therefore subsequently consolidated masses of Granite, have been found penetrating rocks of almost all ages in different parts of the earth.

Primæval Granite, or Primitive Rocks not now known anywhere to exist.—If we admit the hypothesis of the earth having once been a molten globe, as a probable one, it by no means follows that the first formed rocks on the cooled surface would be Granite, even if they contained the constituents of Granite. Judging by the analogy of what takes place now in volcanoes we should expect the first cooled surface to have been a premiceous or scoriaceous lava, rather than a Granite. If the refrigeration went on for a time, one might suppose that beneath such a porous envelope the rocks would become more and more compact and crystalline, and eventually granitic below, and it is of course impossible for us to prove that some of this supposed originally formed Granite, if it ever existed, may not be somewhere or other in existence still. We may, however, very fairly maintain from what we already know of the earth's surface, that none of the rocks now open to our observation can date back their formation to this quasi-fabulous and mythical age of the earth, this pre-geological period of its duration.

Whatever may have been the nature of the primæval crust of the globe, that crust had been more or less completely destroyed and remodelled by the erosive action of water, and the remelting action of heat, before the commencement of even the earliest of our geological periods. The very lowest of the unaltered stratified rocks of which

the age is known, namely, the Cambrian of North Wales and Ireland, are made up of indurated clays, sands, and gravels, which were derived from the waste of previously existing stratified rocks, exactly like themselves.—(*Professor Ramsay, Journal of Geol. Soc.*, vol. ix., p. 168.) The crust of the earth then, was, before that earliest of our periods, made up of stratified and unstratified aqueous and igneous rocks, as it is now made up of them. Just so much of these early rocks are preserved to us as have not been since destroyed by the action either of fire or of water. Over very large areas very early rocks, having been attacked from above, have been eroded and destroyed by the action of water; and the old base on which they rested has been denuded, and is either now exposed at the surface, or has been re-covered by other rocks subsequently deposited upon it. Over very large areas, very early rocks, having been attacked from below, have been so baked, so altered and metamorphosed by the action of heat, and by the many physical and chemical forces which heat has set in motion, as to have been altogether transformed from their original state, and many, of both aqueous and igneous origin, actually remelted down perhaps, and reabsorbed into the molten masses of the interior, in which they either still remain as molten rock, or from which they may have been subsequently reconsolidated as newer igneous rock. Some ancient rocks have been in other areas spared by both these processes; but as these processes are continually going on, and continually shifting their areas of action, it is clear that, in proportion to their antiquity, all rocks must have been more or less affected by them, and that we can reason back to a period in the earth's history, the coeval rocks of which have only one or two undestroyed or unaltered areas still left upon the globe; and going one or two steps still farther back, we arrive at a period of which *none* of the coeval rocks can remain in their original state.

Position and Form of Granite.—Granite generally makes its appearance at the surface in large masses, occupying considerable areas, and extending for a great but unknown depth into the interior. Veins of Granite, often branching and crossing each other, usually proceed from these masses, penetrating the adjoining rocks, and apparently detached dykes, or wall-like sheets, of granitic rock are frequently found in their neighbourhood, running sometimes for several miles in straight lines through other rocks.

Smaller bosses of Granite are likewise not unfrequent in such districts, apparently the tops and eminences of larger masses that are still concealed below.

Granite sometimes forms high mountainous ground, the hills composed of it having commonly a heavy rounded outline and sombre aspect. Sometimes, however, Granite is found as the surface rock over considerable spaces of low gently undulating ground, in which case the

plain is commonly diversified by small rounded knobs and bosses of rock.

Granite is frequently described as the rock forming the axis of mountain chains, or the nucleus of mountain masses.

If it ever form the true axis of a mountain mass, the rocks which rest upon it will dip from it in every direction, and the lowest of the stratified rocks will be found nearest to the Granite, as in fig. 90; where

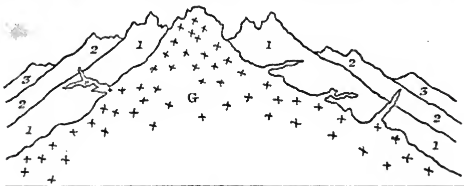


Fig. 90.
Supposed position of granite.

G is a mass of Granite forming the axis of a range, and 1, 2, 3 are the stratified rocks dipping from it in each direction, the lowest or oldest, No. 1, being next to the granite, and the highest or newest, No. 3, the furthest from it. Without attempting to deny that Granite, in some instances, does hold this position, I am yet inclined to doubt whether it has not in many cases been assigned to it as a matter of course, without adequate investigation. I am disposed to suspect that the rocks nearest the Granite having been most altered, and the most altered rocks having been assumed to be the oldest or lowest, this position may often have been taken for granted instead of proved. Having personally examined large granitic tracts in the west of England and south-east of Ireland, in central France, in Newfoundland, at the Cape of Good Hope, and in both eastern and western Australia, in no instance did I ever find a granitic mass forming a true geological axis.

The granitic district in the south-east of Ireland, extending from Dublin Bay to near New Ross in county Wexford, is the largest surface exposure of Granite in the British Islands, being 70 miles long and from 7 to 17 miles wide. There were in this district at least two great geological formations, each consisting of slates or shales and sandstones, and each several thousand feet thick, at the time of the upward intrusion of this Granite. These two formations are known as the Cambrian, which is the lowest or oldest, and the Lower or Cambro-Silurian, which rests in some places unconformably upon the Cambrian. Now in no instance is any part of the lower or Cambrian formation found reposing on or

coming against the Granite at the surface, though it does come to the surface in some places within two or three miles of the Granite, as shewn in fig. 91. The Lower Silurian rocks, however, have been broken into

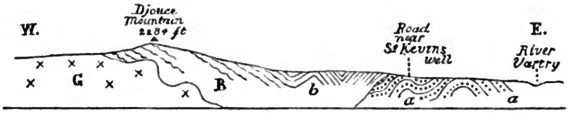


Fig. 91.

Section across Douce Mountain, county Wicklow.

a. Cambrian. B. Silurian altered into mica schist.
b. Silurian. G. Granite.

and altered by the Granite, for a thickness of some hundreds of feet around it, and have been penetrated by Granite veins and protuberant masses; and we are compelled to suppose, therefore, that the Granite must have *come through* the Cambrian rock below, before it can have penetrated into the Cambro-Silurian rocks. Neither, although the main direction of the Granite is approximately parallel to the general strike of the rocks and principal lines of disturbance in the district, does the intrusion of the Granite seem to have been the cause of the general elevation of the country, but simply to have partaken of it, along with the other rocks, and to have had its direction governed by the direction of the forces of disturbance that were acting at the time of its intrusion, or have acted since that time. The Cambro-Silurian slates, which are frequently vertical and greatly contorted over all the district, often appear to dip towards the Granite, at a distance of about two or three miles from its present surface boundary, and to have been only so far affected by the proper elevatory action of the Granite as to be crumpled up or dog-eared against it for a short distance close upon its flanks (see fig. 91).

If we passed from Ireland into Cornwall and Devon, similar conclusions could be drawn from the relations of the granitic masses there with rocks of a still newer date, namely, with those called Carboniferous and Devonian. The Granite penetrates and alters rocks of both those periods, and is therefore newer than both. It has not, however, by its irruption brought up the lowest rock, namely, the Devonian, everywhere on its flanks. On the contrary, where it cuts into and alters the Carboniferous rocks, we are compelled to suppose that it has passed through and left behind the Devonian. Neither does the granite of Cornwall and Devon appear to have acted in any sense as a geological axis or centre of elevation, but simply to have partaken with the rocks of the district of whatever disturbances occurred during or since its

intrusion ; and the granitic veins appear to have been shot into the cracks and crevices of the rocks, which were opened for them by previous disturbances, and not to have made any of those cracks and fissures for themselves. Similar conclusions are derivable from an examination of the Mourne mountain Granite, as shewn by Professor Haughton's observations, and I believe they may be drawn from all other granitic districts in Great Britain and Ireland.

In other parts of the world, as has been said before, Granite is found in the same way to have risen up into, and altered, and sent veins into rocks of still newer date, belonging to the Secondary and Tertiary periods ; and Granite must be forming now wherever molten rock of the proper chemical composition is cooling under the requisite physical conditions, that is, deeply seated under the pressure of great masses of other rock.

Granite more likely to be associated with Older than Newer Rocks from its source being in interior of Earth.—It is doubtless true that Granite is found more frequently associated with the older rocks than with the newer ; in other words, with the lower rather than the higher rocks. The reason of this, however, is clear, from the very source of Granite being in the interior of the earth. Granite, in order to reach the higher, must pass through whatever lower rocks there may be in the way. Many injections of Granite may have proceeded a certain distance from the interior, penetrating only the lower rocks ; but none can have reached the upper without penetrating the lower.

That Granite should be most frequently associated with the lowest rocks follows, too, from the very nature of Granite. Molten rock that reached, or came near to the surface, would not, on consolidating, form Granite, but some other kind of igneous rocks—a felstone trap, or a trachytic lava, as the case might be.

There is, also, still another reason why granite is found principally in connection with rocks that have formerly been deep-seated, and that is, that all Granite now found at the surface must be there in consequence of vast denudation having taken place, by which great masses of other rocks have been removed, together perhaps with much of the Granite that once existed above the present surface. This denudation, of course, exposes the lower rock to view, while the parts of the higher

Fig. 92.

The dotted lines represent the former extension of stratified rocks, equally penetrated by *g*, the granite, but the penetrated parts removed by denudation.

rocks that were perhaps equally penetrated by the Granite have been swept off and removed (see fig. 92); the other parts which remain being now at a distance from the Granite, and shewing no signs of such penetration.

It is therefore where the lowest or oldest rocks come up to the surface that we should expect most frequently to meet with surface Granite, as we find to be the case.

Relative Age of Granite Masses as proved by that of their Denudation.—It has already been said that the Granite of the south-east of Ireland penetrates no rock more recent than the Lower Silurian, while that of Cornwall and Devon intrudes into the more recently formed Devonian and Carboniferous formations. That of the Mourne mountains in the north-east of Ireland also penetrates and alters the Carboniferous Limestone. These facts would in themselves raise a presumption that the Cornwall and Mourne mountain granite was of much more recent origin than that of Leinster. Taken by themselves, however, they are not sufficient to prove this relative age, since it might be supposed that they were contemporaneous, but that the Leinster Granite did not come through the lower rocks so as to reach into the upper, while the Granite of the other localities did so.

We can, however, by examining the relations of the Old Red Sandstone and Carboniferous Limestone to the Granite of Leinster, prove that that Granite is much older than those formations, inasmuch as it was not only perfectly consolidated before they were formed, but actually denuded and brought to the surface, as shewn in the preceding chapter.

Before the commencement of the Carboniferous period the Leinster Granite formed the bare surface of some of the dry land, just as it now forms that of the Wicklow mountains, and the bare floor of some part of the sea, just as it does now on the south side of Dublin Bay, and would to a greater extent if Ireland were to sink down 2000 feet or so. The Old Red Sandstone and Carboniferous Limestone were deposited on this bare surface, and included fragments of it, just as rocks would do now if it were to be so depressed and deposition to take place over it.

But if we can prove thus that the Leinster Granite was consolidated long before the Carboniferous period, we can also prove that that of Cornwall, and that of Ulster was still molten during that period, and even after it, or at all events till towards its close, since it penetrates the rocks that were formed during that period.

It is probable that the Granite of the two latter localities is older than the formation of the New Red Sandstone, though no locality is known where rocks of that period rest on the bare Granite as the Old Red does on that of Leinster.

Granite Veins.—Granite veins often differ sensibly in lithological

character from the parent mass which they proceed from; and sometimes the external margin of the Granite differs also from its deeper and more central portions. Veins very frequently become more fine-grained, and they lose commonly the mica, and sometimes more or less of the quartz, which the mass contains, becoming less crystalline and more earthy. Sometimes they take up into their constitution additional materials, derived from the rock which they penetrate and traverse. A striking instance of this latter occurrence is described by Professor Haughton in his paper in the *Journal of the Geological Society*, London, vol. xii., pp. 193 and 197, and previously quoted when speaking of the lithological characters of Granite at p. 94 of this Manual.

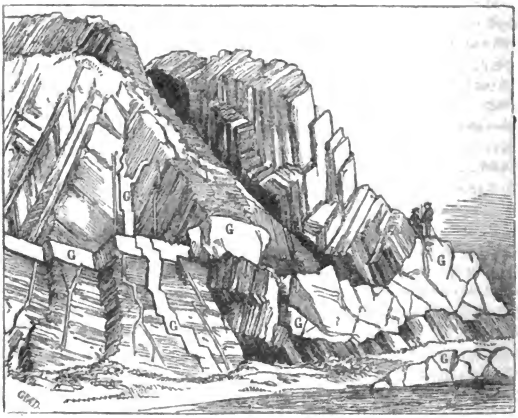


Fig. 93.

Granite veins traversing Lower Silurian slate (there altered into mica schist), on the shore beneath Killiney Hill, county Dublin. The larger masses of granite are marked G.

Fig. 93, drawn by M. Du Noyer, represents Granite veins as seen on the shore of Killiney, near Dublin, traversing a mass of the dark Lower Silurian slate rocks, which are there altered into glittering mica schist. The little bands of fine-grained gray gritstone, indeed, which are interstratified with the clay slates, are not changed except by a slight additional induration, probably on account of their being almost entirely siliceous, but the clay slates are as brilliant silvery mica schist as can be desired; moreover, some of their layers are crowded with beautiful stellated forms of staurolite, or some allied mineral which has been

developed by the metamorphism in those layers which had the requisite constituents to form the mineral, while they are absent from the intermediate layers.

These schistose rocks are entirely surrounded by the Granite, and rest in hollows of it, although, as may be seen in the sketch, their beds dip down on to it. They are traversed by large and small veins of Granite, one vein being in one place crossed by another of subsequent date, though not probably of much later date, since the whole may have been the result of one continuous and perhaps long continued action.

Other veins are to be found in Granite itself, different in character from the surrounding rock, such as veins of eurite (see *ante*) traversing coarsely crystalline and highly micaceous Granite. Such veins may sometimes be due to subsequent intrusion of molten matter into the cracks of the Granite; and when they traverse not only the Granite but the adjacent slates or other aqueous rocks, as in the above example, they are obviously intrusive.

In other cases, however, they seem to have been the result of a mere local difference in the aggregation of the minerals during the consolidation of the rock. Instances occur of granite veins not more than three feet wide penetrating the mica schist at Killiney, near Dublin, the general mass of such veins being ordinary coarse-grained micaceous Granite, but parts of them suddenly changing into fine-grained, almost compact rock (or eurite), in transverse bands of irregular shape. These bands look as if they were subsequent veins injected into the other Granite; but as they are strictly confined to the Granite veins, and do not penetrate the adjacent slates, it is impossible to attribute such an origin to them.

Moreover, in the adjacent Granite, large irregularly-shaped masses of this compact eurite are to be seen coming in quite suddenly, but with no resemblance to a subsequently intruded mass.

I believe, then, that some of the veins in a granitic mass are merely veins of segregation, and not subsequently introduced.

Other veins, however, are doubtless of subsequent origin, intruded both into the Granite and adjacent slates, but even in these cases it is probable that they are not of a date long posterior to the intrusion of the main mass of the Granite. It is possible that, on the first consolidation of the upper portion of the Granite, that which was in contact with the superincumbent rock, cracks and fissures might take place, into which injections of the yet molten rock below might be forced. The upper consolidated part of the Granite, although no longer fluid from heat, might yet retain a very high temperature—might, for instance, be red-hot, so that the veins injected into it might be soldered, as it were, firmly to the walls of the fissures.

The difference in texture observable in some of these veins might be due to the different rate at which they had cooled so as to solidify; they might have cooled down to a red-heat, for instance, or any other requisite temperature, more rapidly than the general mass of the Granite had cooled down to that temperature, and hence the size of their crystalline particles might be different from that of those in the main mass of the Granite.

The "elvans" of Cornwall are veins of quartziferous porphyry, differing from Granite chiefly in the absence of mica. Similar elvans are abundant also near the Granite of Leinster, and probably in the neighbourhood of all other granitic masses. They are obviously veins derived from the Granite, since that particular variety of rock only occurs in districts where Granite also occurs, and they are generally more numerous as we approach the Granite. They are often traceable in nearly straight lines for some miles, although only a few feet in width, several of them sometimes running parallel to each other for such a distance, with intervals of two or three or more hundred yards between them. They often coincide in strike with the slate or other rocks in which they lie, though they generally cut obliquely across the dip of the beds, and sometimes also across their strike. They often alter the rocks in contact with them; not, however, like the larger Granite masses, by converting them into mica schist, but merely producing a greater induration, a more minute joint fracture, and a brown ferruginous tinge, giving them what might be called a "burnt" aspect.

In the Leinster district the rock of these "elvans" is more like that observable in the small outlying bosses of Granite which just shew themselves through the slate in the country between the Granite hills and the sea, than it is to the Granite of the "main chain."

Professor Haughton, in his paper in the *Journal of the Geological Society*, vol. xii., and that which he published, conjointly with myself, on the south-east of Ireland, in the *Transactions of the R. I. Academy*, vol. xxiii., part 2, shews that the feldspar of the main chain Granite is chiefly or entirely orthoclase or potash feldspar, while that of the outlying Granite bosses is very various, some of the Granites containing more soda or iron or alumina than others. He attributes this to the various impurities which have been incorporated with these granitic masses while they were yet in a state of fusion.

These differences are exactly what we should expect in veins of molten matter proceeding from a large homogeneous mass through a great thickness of other rocks which varied in composition, and therefore absorbing into themselves different materials on their passage.

Apparent interstratification of Granite and Mica Schist, etc.—When granitic veins are numerous and close together they often seem at the surface, or in exposures of small depth, as if there were alternating beds

of Granite and Mica schist. This is actually stated to be the case by Mr. Weaver in his excellent paper on the geology of the south of Ireland (in the fifth volume, p. 142, *et seq.*, of the *Trans. Geol. Soc.*, 1st series) with respect to the Granite and Mica schist of the eastern flank of the Wicklow mountains.

An examination of the borders of the Leinster Granite, however, with the maps and sections of the geological survey, will shew that this is merely the result of original irregularities in the undulating surface of the Granite, and of the veins proceeding from it at the time of its irruption.

Original Irregularities in Surface of Deep-seated Mass of Granite, and varied Appearances shewn by varied Denudation.—The Granite being forced from below, upwards, into a thick overlying mass of Cambro-Silurian rocks, in and below which it ultimately consolidated, the internal force which pressed it upwards caused not only injections of the yet molten rock into the cracks and fissures of the superincumbent mass, but undulations in the general surface of the Granite, some parts of the overlying mass being heaved up, and others sinking down into the yet molten Granite. Urged by the force below, the molten rock would burrow upwards and sideways, eating away support after support of the mass above it, and in some cases actually melting them down perhaps, and absorbing their materials into itself. We should naturally suppose that as long as the granitic matter remained completely fluid its motion would be continuous, but as it cooled and passed into a pasty state, that motion would become more and more sluggish until it finally ceased to move, but retained the undulations in the form of its surface which were last impressed upon it.

The upper surface of the Granite mass on its final consolidation might thus be an excessively irregular one, with protuberant mounds or ridges, and deep hollows and indentations, while the beds of the superincumbent mass would not be likely to conform at all to this irregularity of surface, but would often dip directly down on to it, or abut against it in all kinds of ways, and to any amount of inclination. When such a surface was ultimately brought up and denuded so as to form the surface of the ground, it might readily produce the appearance of interstratification of sheets of Granite with beds of the other rocks, or of the other rocks having been brought by faults abruptly against masses of Granite and other deceptive forms, very likely to mislead the observer, unless he look back to the probabilities of the original case.

It may often happen then, even where beds of aqueous rock are highly inclined, or absolutely vertical, that the Granite may be at no great distance below the surface, and if the rocks exhibit marks of metamorphism or the occurrence of granite veins, those circumstances may be taken as good evidence for the proximity of the Granite, not-

withstanding that no large granitic mass shews itself at the present surface for perhaps several miles. (See fig. 94.)

These ideas respecting the original subterranean form of the surface of Granite masses are strongly corroborated by the relations between the Granite of the Leinster chain, and the associated and partly included masses of Mica schist in different parts of its range, those relations often varying according to variations in the surface of the ground, or in other words, according to the extent of the denudation that has affected them. In those parts where the Granite forms lofty hills, the Mica schist spreads far up on the flanks of those hills, and on the very loftiest, such as Lugnaquilla (which is over 3000 feet above the sea), large patches of Mica schist occur even on the summit, so that the surface exposure of Granite is there narrowest and most interrupted. Had the hills been left another 500 or 1000 feet higher, the Granite would apparently have been entirely concealed there by masses of Mica schist stretching completely over it.

On the other hand, where the Granite forms low ground, as about Tullow and Hacketstown, its surface exposure is there by far the widest, and all the central part of it is completely free from patches of mica schist.

It is obvious that these differences are the result of the different amount of denudation that has acted on the Granite. Where the ground is loftiest, we have the nearest approach to the original surface of the Granite and its original covering of other rock ; where the denudation has cut down deepest, so as to form low ground, there we get deeper into the Granite mass, or further from its original surface, to a depth, indeed, to which no mass of Mica schist could penetrate, unless it were altogether detached from the overlying mass, when it would be probably melted down, and its materials absorbed and dispersed through the mass of the molten matter.

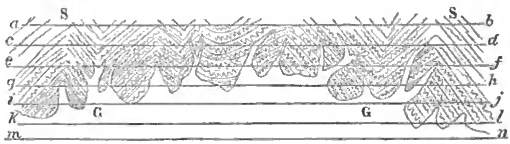


Fig. 94.

Ideal section representing the relations between G, a granite mass, and S, a superincumbent mass of slate rock ; the lines *a*, *b*, and *c*, *d*, etc., representing different surfaces formed by denudation.

Fig. 94 may be taken as a diagrammatic way of illustrating these views, G G representing a mass of Granite gradually forced upwards

into the mass of slate, S S, which had been already disturbed and tilted in various directions. The Granite would ultimately consolidate with a variously irregular surface, from which numerous veins might proceed, somewhat in the way delineated in the figure.

A metamorphosis into Mica schist and Gneiss also would take place in the parts of the slates nearest to the Granite, gradually fading away as we recede from its general outline. This is attempted to be represented by the waved and zig-zagged lines shewn in the parts of fig. 94 near to the Granite.

If subsequent denudation produce the surface *a b*, none of the Granite veins may be seen on it, although part of the slates may be slightly metamorphosed, so as to be called "talcose" perhaps. If the denudation be continued, so as to produce the surface *c d*, a few veins will reach it; these would become more numerous as the surface *e f* was reached. The surface *g h*, and intermediate surfaces between *e f* and it, would expose some of the Granite with many patches of Mica schist upon it, and apparently dipping down into it, but not reaching far, as would be shewn by their absence from the surface *i j*, when that was reached. The width of the Granite area, too, would be much greater on the surface *i j* than on *g h*, and would necessarily increase with the depth of the denudation, the Granite veins being seen then only on the sides of the area, and no patches of Mica schist occurring far from those sides, these facts becoming still more marked as the denudation successively reached the still lower levels, *k l*, and *m n*.

This diagram may be taken as a general exposition of the facts of the case, with respect to the exhibition of the Leinster Granite, except that the supposed surface lines *a b* and *c d*, etc., are drawn as straight parallel lines, instead of variously undulating ones. Judging from the maps of the geological survey, the explanation would apply also to the Cornwall and Devon district, and I believe it will be eventually found applicable to all other granitic districts, when they are surveyed with the same accuracy and minuteness that has been devoted to those above named.

CHAPTER XVIII.

TRAPPEAN ROCKS.

1. *Form and Mode of occurrence of Trap Rocks.*—The trappean rocks may be especially characterised as overlying rocks when compared with the granitic class; but, inasmuch as they always proceed from below, it is obvious that every overlying mass of igneous rock must have a connection with some underlying mass by means of an intrusive pipe, dyke, or vein (see fig. 95). The terms "pipe" and "vein" sufficiently explain themselves. "Dyke" is a North British term for a "wall;" it is sometimes by miners applied to a mere fault or fissure, but by geologists is always understood to mean a wall-like mass of igneous rock filling up a fissure in other rocks. A dyke may come up through any kind of previously existing rock, whether igneous or aqueous, trap dykes sometimes traversing granite, and overlying masses of trap resting on that or any other kind of rock whatever.

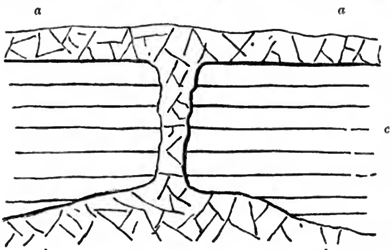


Fig. 95.

Overlying trap proceeding from underlying mass.
a, The overlying igneous rock.
b, The underlying igneous rock.
c, The previously existing rock, whether igneous or aqueous.

They may also reach and flow along all kinds of places—the surface of the dry land, when they become volcanic rocks, and would be called lava; the bottom of the sea, when they would probably be called lava or trap, according to its depth and the circumstances of time and pressure under which they cooled; and in between the beds of aqueous rocks at different depths, or perhaps between the horizontal or other joints of previously cooled igneous rocks, whether granitic or trappean.

Those portions of trap rocks which have spread out upon the

bottom of the sea, and have thus become buried between two consecutive deposits of aqueous matter, are called "contemporaneous traps."

In the old Silurian districts of the British Islands great sheets of *felstone* and of *feldspathic ash*, making sets of beds many hundred feet thick, are thus interstratified with the aqueous rocks, and have since suffered with them all the accidents of flexure, contortion, and fracture that subsequent disturbing forces have brought upon those districts. Some fine-grained traps and ashes have undoubtedly been even affected by slaty cleavage and made into trappean slate, though, as some of them, like the clinkstones of Mont Dor and Velay, may assume a finely laminated or slaty structure on cooling, this character requires to be very carefully observed before it is attributed to the same cause that cleaved the aqueous rocks.

Contemporaneous or bedded felstones with accompanying ashes, as well as intrusive masses of felstone, occur also in the south-west of Ireland, in the Upper Silurian rocks of the Dingle Promontory, in the Old Red Sandstone near Killarney, and in the Carboniferous slate of Bearhaven.

Greenstone likewise occurs, with or without ash, in contemporaneous beds as well as in veins and dykes, and as intrusive sheets that in some places take the form of beds.

Intrusive sheets of greenstone have been traced for miles in the rocks of North Wales, during the geological survey, running regularly between two sets of beds, as if they were contemporaneous traps, till at length they were found to cut obliquely up or down, and run on between other beds.

A large sheet of greenstone, varying in thickness from 20 to 60 feet at least, has been found, by mining, to spread over an area of at least twenty square miles in the South Staffordshire coalfield, lying in one part of the district at a depth varying from 30 to 70 feet below the "Bottom coal," but in another part cutting up through that coal and spreading over it, and sending up dykes and protuberant bosses in some places into still higher measures.—(*See Mem. Geol. Surv.*, S. Staff. Coalfield, 2d ed., p. 127.)

In such cases as these, we may suppose that having been forced up through previously-formed fissures to a certain height, the molten rock then met with such an opposition above, that it was as easy for the force which was impelling it to lift the beds above as to break through them. The planes of stratification then became those of least resistance; some horizontal cavities or some marked division between the beds perhaps was taken advantage of, and the molten stream, beginning to flow in, was injected with sufficient force to float the mass above upon its surface.

Greenstones occur likewise in contemporaneous beds interstratified

with both "ash" and aqueous rocks. The beds of "toadstone"* in the limestone of Derbyshire form one instance of this, and other cases occur abundantly in other parts of the British Islands and in Ireland, as will be mentioned presently.

Distinction between Contemporaneous and Intrusive Trap.—As it is sometimes not very easy to distinguish between injected sheets of trap and contemporaneous beds of it, it will be useful to examine those circumstances which will enable us to do so.

If a sheet of trap rock (whether felstone or greenstone), after running for some distance between two certain beds, cut up or down and proceed between other beds, as in fig. 94, it is obviously intrusive and not contemporaneous.

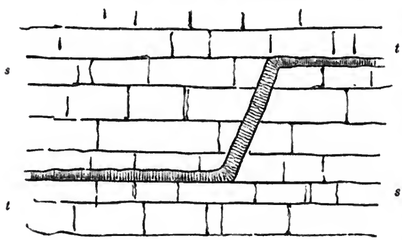


Fig. 96.
s, Stratified rock.
t, Trap running partly between, partly across the beds.

If the beds above a sheet of trap be as much altered or "baked" by the igneous rock as those below, or if it send any veins up into the beds above it, it is equally plain that it must be an intrusive sheet.

If, however, the trap runs regularly between two beds, and the bed below the trap be altered, while that above it, composed of equally alterable materials, is quite unaffected, we may conclude that the trap was poured out and flowed over the surface of the lower bed, and that the upper bed was subsequently deposited upon it; in other words, that the trap is contemporaneous and not intrusive as regards the beds in that place.

This conclusion would be confirmed if the upper surface of the trap be rugged and uneven, and if the stratification and lamination of the bed above conformed to these rugosities, as suggested in fig. 97.

In the "toadstone" of Derbyshire globular masses of its upper surface are often almost completely included in the superincumbent limestone, clearly shewing that the limestone was deposited at the bottom of the sea on the uneven surface of the cooled trap.

* Toadstone is a local name, either given because the rock often resembles a toad in colour, or derived from the German word "todstein" or "dead stone," because the lead veins "die out" on approaching the toadstone, and were supposed not to recur beneath it.

If, again, the bed above the trap contained any fragments clearly derived from the erosion of the trap, it would prove the trap to be a contemporaneous one. The Carboniferous Limestone of the county

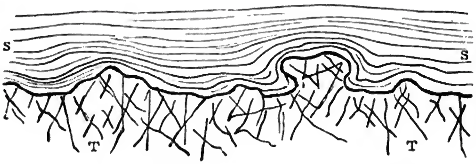


Fig. 97.

s, Stratified rock, the lamination of which conforms to the rugged surface of *t*, a trap, in such a way as to shew that it was deposited upon it.

Limerick includes great beds of trap, and the limestone beds immediately above these are often full of little grains and fragments of the trap, shewing that the trap was in existence before those beds of limestone were formed over it.

When beds of trap (whether purely feldspathic or feldspatho-hornblendic) are clearly interstratified with beds of "ash" or "tuff" of the same character, whether that ash were subaerial or submarine ash,* it becomes almost certain that the trap is contemporaneous; for that ash is clearly derived from some contemporaneous trap somewhere, and the chances would be greatly against a sheet of similar trap being subsequently injected into those ashes, without producing in them great and obvious alteration, or cutting them with dykes and veins so as to clearly shew its intrusive character.

Even should the ash shew a considerable amount of alteration from its original state as a mechanical deposit, such, for instance, as the production of crystals of feldspar through its mass, it would not be conclusive evidence against its being an "ash," or against the contemporaneous age of the trap beds associated with it, since such alteration might be the result of a subsequent general action, which had produced a greater effect on the "ash" than on the other rocks, because its nature made it more easily impressible, and more open and liable to change than the solid igneous or the simple and more homogeneous aqueous rocks.

Instances also occur of a genuine "ash" looking like a porphyry

* The student must regard the term "ash," introduced by Sir H. De la Beche as merely an English synonym of the Italian word "tuff," or "tufa," when the latter is applied to igneous materials. The advantage of using the term "ash" is the avoidance of the ambiguity arising from "tufa" being sometimes applied to calcareous or other depositions of a soft friable character.

from containing crystals of feldspar or hornblende that were not innate crystals formed in it, but deposited as slightly worn and rounded crystals along with it.

The Traps and Ashes of the Lower Silurian Rocks of North Wales.—In some parts of North Wales there are great irregular bosses and mountainous masses of trap of various kinds, apparently the centres or foci of eruption, from which proceed huge continuous sheets of felstone and other kinds of trap spreading over great areas and interstratified with "ash," sandstone, and slate. Still more widely-spread sheets of "ash," sometimes hardly distinguishable from trap when near the igneous foci, become thinner and more obviously mechanical, more completely conglomeritic or brecciated, or more calcareous and more regularly bedded as we proceed from these foci. The whole of these rocks are cut through and penetrated in different places by subsequently-formed dykes, veins, and intrusive sheets of other traps (greenstones, felstones, syenites, elvanites, etc.), altering the rocks more or less entirely according either to their chemical composition or to the mass of the intrusive trap, and thus completing the complexity and confusion which the geologist has to unravel.*

Not only were the rocks thus complex at their first formation, but they have since been greatly upheaved and disturbed, thrown into many and complicated folds, and broken by many faults running in various directions, heaving and dislocating the beds now one way, and now another, and with ever varying amounts, sometimes throwing them as much as three or four thousand feet from the level of the corresponding beds on the other side of the fault. In addition to this, the country has been worn and eroded into valleys and glens, with precipitous cliffs and crags, separated by more or less inaccessible ravines; and as the rocks are frequently disguised by partial decomposition, and concealed over wide intervening spaces by soil, by vegetation, or by superficial accumulations of gravel, clay, and sand, it will be readily understood that it is no easy or unlaborious task, though often a healthy and delightful one, to trace out all this complexity, and restore order to all this confusion, to delineate the outlines and positions of the rocks as they now are, and to reason back to their original state, and to the causes which produced them.†

* See the "Memoirs" of Professor Sedgwick in Proceedings of Geological Society; also his "Letters to Wordsworth" in the Guide to the Lakes, and "Introduction to Palæozoic Rocks," 3d Fasciculus; also Murchison's "Silurian System," and the maps and sections of North Wales, published by the Geological Survey.

† I believe I am correct in saying, that some districts of North Wales were visited and revisited not less than ten times, during the progress of the Geological Survey, by *the same observer*, before their structure was rightly comprehended. This was more especially the case in some of the wilder districts, which required some hours' walking "over moor and mountain" before they could be reached.

The Trap District of the Limerick Basin.—Ireland presents us with an example of interstratified aqueous and igneous rocks in county Limerick, which is perhaps more interesting and even more instructive than North Wales or other mountainous regions, because it has been less disturbed, and is much more easily examined. The aqueous rocks, too, are chiefly limestone, so that there is no difficulty in distinguishing them from those of igneous origin. The north-eastern part of Limerick and neighbouring parts of Tipperary are occupied by a broad mass of hills, of which Slievkimalta or the Keeper, 2278 feet, is the loftiest. These are made of Lower Silurian rocks covered on their flanks by a coating of Old Red Sandstone about 500 or 600 feet thick, which dips down on all sides beneath a plain formed of Carboniferous Limestone. Towards the south and south-west, other hills, such as Slievnamuck and the Galtees (of which Galtymore is 3015 feet high), the Slievreagh and the Knockfeerina ranges, rise from the plain at a distance of about 15 or 20 miles from the foot of the Keeper group. These other hills are all made externally of Old Red Sandstone rising up from beneath the Carboniferous Limestone, and enveloping thick and massive nuclei of contorted and denuded Lower Silurian rocks. The centre of the rich plain between these mountainous hills is diversified by groups of less lofty but often steep and rough-looking hills, rising into craggy knolls some 600 or 700 feet high, while much of the country about them consists of alluvial flats not more than 100 feet above the sea.

These craggy hills are chiefly composed of trap rock, some of them a red syenitic porphyry, others a dull purple, often earthy-looking trap, with or without crystals of feldspar, others of greenish and blackish colours. Some of them might perhaps be called feldspar-porphyry, or compact feldspar, others greenstone, melaphyr or basalt.* Some of these traps become in some places regularly and beautifully columnar, others are quite vesicular and scoriaceous, the vesicles being often filled with crystals, sometimes of white calc-spar, sometimes of zeolite, and sometimes even of quartz, and thus forming an amygdaloid.

Some of the vesicular portions make rude layers between bands of compact or crystalline trap, as if they had formed the top and bottom of different flows of lava, like those described by Sir C. Lyell in his paper on Etna in the 148th vol. of the *Philosophical Transactions*, p. 732.

Associated with the porphyries and other traps are large irregular deposits of "ash," consisting of beds of coarse and fine grained materials obviously derived from the traps, and such as are found nowhere else in the neighbourhood except in the traps. Some of these beds consist of coarse conglomerates, with rounded blocks of trap and limestone, some

* The chemical analysis of these different kinds of trap would be a very interesting subject of inquiry, but no chemist has as yet undertaken it.

of which are as large as a man's head, and many as large as the fist. Other beds are composed of very regular parallel laminæ of grains of trap, many of which are vesicular, varying in size from peas down to pin-heads, and others still more minute, the coarse and fine layers often alternating in such regular bands, of about half an inch in thickness, that they have been likened, as they appeared in the quarry, to the edges of a pile of planks in a timber-yard. These "ashes" are generally either purple or green, and some of the green kinds, especially, become still more fine-grained, so that the particles are ultimately undistinguishable even by the lens, and the stone becomes a compact green rock, like a rude porcelain. Some of this compact stone forms layers interstratified with coarser layers, but in other cases it alternates with layers of limestone, the two kinds of rock being blended together so that hand specimens may be got containing layers of both. This stone looks as if it were composed of the finest and most impalpable volcanic dust or powder consolidated into a rock.

Not only do beds of this compact rock contain layers of limestone, and beds of limestone contain layers of this compact ash, but there occur alternations of coarser ash and limestone, as well as rounded blocks of limestone in the ash, and layers of chips and fragments of the trap in many beds of limestone.

Some of the great masses of trap, 800 or 1000 feet thick, are found, when followed along their strike, to split up and let in alternations of beds of ash and beds of limestone with beds of trap, shewing that the greater uninterrupted masses of trap, even some of highly crystalline porphyry, were in reality formed by successive flows of molten rock at the bottom of the sea, and that, where each of these flows terminated or became thin, accumulations of ash or limestone took place on the sea-bottom, in the intervals between the outpouring of one flow and that of the next, so as to cause these interstratifications. Pallas Hill is a conspicuous example of this occurrence. Instances are not wanting of intrusive dykes cutting through both aqueous and igneous rocks, but being, of course, more readily distinguishable when they traverse the aqueous than the igneous rocks.

In the centre of the district around Ballybrood is a patch of Coal-measures (one of those alluded to before at p. 286), shewing that between this and the foot of the Old Red Sandstone hills we have the whole series of the Carboniferous Limestone.

These Coal-measures are in one place penetrated by intrusive trap, and they rest on one side on a thick mass of bedded trap, which is the trap of which Pallas Hill is formed, while, on the other side, they repose on the top of the Carboniferous Limestone.

This upper trap band now forms the half of an oval basin about six miles long. The trap dies away in the limestone towards the north-

west, but becomes so thick towards the south-east as to have prevented the deposition of the uppermost beds of the limestone there, and not to have been covered in that part by any aqueous rock till the Coal-measures were deposited. Beneath this upper band of trap and ash, which swells out to a maximum thickness of 1200 feet, limestone is found with a thickness of about 800 or 1000 feet, below which is another great band of trap and ash often attaining a thickness of 1100, and sometimes of 1300 feet. This forms now a regular oval ring of about twelve miles from east to west, and six miles from north to south, dipping from all directions towards the central district of Ballybrood.

From beneath this rises the lower part of the limestone, the beds of which spread round it for some miles on all sides. Towards the west and north-west, these lower limestones undulate, so as to bring in several irregular outlying basin-shaped patches of the bedded traps and ashes above it with parts of the upper limestone over them. In other directions, however, they rise gently but steadily out, so as to bring up lower and lower beds as we recede from the traps. It is very remarkable, that on the south of the trappean basin we get a line of five intrusive bosses of trap, that rise up through the lower limestone, and one at about the same distance north of the trap basin. These look like some of the volcanic foci from which the bedded traps were derived, the old roots, as it were, of the submarine lava flows, exposed to view by the denudation of the limestones and traps that once covered them. Other foci or irruptive masses are doubtless concealed beneath the existing beds of trap in the central parts of the basin.

Full descriptions of this district will be found in the sheets of the map of the *Geological Survey of Ireland*, Nos. 143 and 144, 153 and 154, and their accompanying printed explanations, and in the sheets of Longitudinal Sections, Nos. 6, 7, and 8. It is one of the most complete examples I know of the interstratification of igneous and aqueous rocks, and of the exposure of an old submarine volcanic district by the elevation and denudation of the beds.

When examining some of the traps and ashes of the district, I was often reminded by them of those I saw in the year 1845 in Torres Straits (see *Voyage of H. M. S. Fly*, vol. i., p. 204). Several islands there, of which the native names are Erroob, Maer, Dower, and Waier, rising to heights of 600 and 700 feet above the coral reefs by which they are surrounded, are composed partly of dark lavas and partly of very regularly stratified volcanic sandstones and conglomerates, such as we now call "ash." These contained many rounded pebbles of limestone, apparently derived from the coral rock* through which the

* Although these rounded lumps of limestone in the "ash" of the extinct volcanic islands of Torres Straits looked very like the coral rock, it could not be certainly proved that they were so. The islands had suffered a good deal from erosion and denudation, no actual

eruptions had taken place, and the lava pebbles were often bound together by strings of calcareous cement, like those of Limerick. The beds of volcanic conglomerate in the Torres Straits islands are certainly highly inclined, with a quaquaversal dip from their centres, while the coral reefs around them are horizontal, and so far they do not agree with the old Limerick rocks, in which the beds of both are conformable to each other.

But it is to be recollected that in Limerick we have none of the subaerial islands or cones preserved, even if any such were formed, but only the submarine beds that were deposited round the volcanic vents. When the coral reefs come to be elevated into dry land, and partly denuded, beds of "ash" may very likely be found horizontally interstratified with beds of coral limestone, or other marine deposits, in the parts which are now deep beneath the sea-level.

Association of Felstone and Greenstone.—In some of the Lower Silurian trap districts of North Wales and Ireland, I have occasionally been struck with the association of felstone and greenstone, it being rare to find any considerable mountain mass of felstone without irregular patches of crystalline greenstone disseminated about it. The irregular outline of these greenstone patches gave them the appearance of being subsequently intrusive into the felstone, but the frequent association of the two has sometimes led me to speculate on the possibility of the two rocks having been part of the same molten mass, and having settled or segregated apart from each other on the cooling of the whole. The variety in the traps of the Limerick district, and the difficulty in tracing any distinct line of demarcation between those different kinds, leads us towards a similar conclusion. There seems no very cogent reason why we should necessarily suppose the whole of any molten mass to have been completely homogeneous ; but granting that it was so, is it not possible that, when a large mass of trap commences to cool, a separation may take place among its ingredients, and one more fusible portion of it may be segregated from the rest, and thus one or more local centres might be established, into which the greater portion of the more fusible bases (silicates of lime and iron) should be concentrated? These local patches, on the ultimate complete refrigeration of the whole, would form some variety of greenstone, while the rest of the mass would be more purely feldspathic. They *might* even retain their fluidity for a greater time than the rest, and during its cooling and

cone with internal crater remaining, though their outside cliffs were not so lofty or precipitous as those of St. Paul's Island, in the South Indian Ocean, of which the central crater still remains, and still exhibits signs of the remains of activity in the hot water that trickles over the stones of the beach. The Torres Straits islands had doubtless been much protected from marine denudation by the surrounding coral reefs, and had suffered chiefly from atmospheric waste. St. Paul's has always been exposed to the unbroken swell of the Indian Ocean.

consequent contraction, they might perhaps be squeezed in various directions into its fissures, and then consolidate more rapidly than the mass had done, and thus acquire a different texture, as well as a different composition.

Trap Dykes and Veins.—Veins and dykes of trap are so common among all kinds of rock, that it is unnecessary to dwell on them at great length.

One of the most remarkable examples of a trap dyke anywhere in the world perhaps, is the one so well known in the north of England as the Cockfield Fell dyke, a nearly vertical wall of trap, 18 or 20 yards thick, which runs in a nearly straight line from north-west to south-east, for a distance of about 70 miles, cutting through all the rocks from the Coal-measures into the lower Oolites, and baking the Lias and every other rock it meets with for a distance of some yards from its sides. Its effect on one of the coal beds under Cockfield Fell, is well described by Mr. Witham in the *Transactions of the Natural History Society of Newcastle*, vol. ii., p. 343. The coal, I believe, is originally about 6 or 8 feet thick, one of the principal bituminous coals of the district. In approaching the dyke, it begins to be affected at a distance of 50 yards from it ; it first loses the calcareous spar which lines the joints and faces of the coal, and begins to look dull, grows tender and short, and also loses its quality for burning. As it comes nearer it assumes the appearance of half-burnt cinder, and approaching still nearer the dyke, it grows less and less in thickness, becoming a pretty hard cinder only 2 feet 6 inches in thickness. Eight yards further it is converted into real cinder, and more immediately in contact with the dyke, it becomes by degrees a black substance, called by the miners " dawk," or " swad," resembling soot caked together, the seam being reduced to 9 inches in thickness. There is also a large portion of pyrites lodged in the roof of that part of the seam which has been reduced to cinder.

The South Staffordshire coalfield is full of such dykes and veins, especially about the foot of the Rowley Hills, which are capped by columnar basalt. Fig. 98 is an example of one of these in the Grace Mary Colliery, belonging to Dr. Percy, which was carefully drawn to scale with a measuring tape. It represents about 100 yards of the side of one of the gate roads cut in working the Tenyard coal ; that coal being at one part partially replaced by a white sandstone with Carbonaceous veins, which is called by the colliers " rock and rig." Both coal and sandstone were traversed by the trap, which was also white. It is the trap which, as previously mentioned at p. 79, was found on analysis by Mr. Henry to contain 9.32 per cent of carbonic acid, and 11.01 per cent of water, being probably an altered form of the greenstone below ; some of the silicates of the original trap having become partially converted into carbonates, and hydrated.

The coal is also altered by the presence of the trap, since in its vicinity it has lost its bright lustre and its regular "face," has parted with much of its bituminous or inflammable character, and more nearly resembles anthracite than bituminous coal, though different from both, being often full of concretions of iron pyrites, or of carbonate of lime, or other minerals. In the language of the colliers, the coal is said to be "blacked," and to be "brazil," or "brassil," and consequently not worth the trouble of "getting."

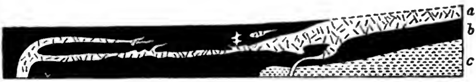


Fig. 98.

a, "White rock," trap. *b*, Altered coal. *c*, Sandstone.

See "Geology of South Staffordshire Coalfield," in which other examples are given, shewing in some places that the alteration of the coal has proceeded but a very slight distance from the trap, sometimes not more than a few inches.

The limestone of the county Limerick is, in like manner, but very little altered even in those places where beds of trap have flowed over it, or intrusive masses come in direct contact with it.

Plateaux of Basalt.—Basalt is rarely, if ever found as an underlying rock, and not often as an intrusive sheet. It occurs commonly either as a dyke or as an overlying mass. One of the most celebrated plateaux of basalt is that on the north-east of Ireland, covering almost the whole county of Antrim with a mass which is in some places 900 feet thick, and 50 miles long by 30 wide, or about 1200 square miles in area. The basalt occurs in many partial and interrupted sheets, or flows, some of which are quite amorphous, either compact or amygdaloidal, while others are beautifully columnar; one of the columnar beds dipping gradually into the sea on the north coast is known as the Giant's Causeway. On the north-east coast of Antrim, the basalts are interstratified with several widely-spread beds of basaltic ash, some of which are locally known as "red ochre" beds; others form a kind of clay or wacké. Beds of lignite also occur in thin beds of clay, derived probably from other sources.

The basalt itself is often traversed by dykes, each of which is probably the feeder from which some overlying bed of basalt was poured out. These dykes are still more numerous, or are more readily observable in the chalk and other beds below the basalt, which crop out round the basaltic area. They vary in width from 2 or 3 feet, to 8 or 10 yards, and are traceable sometimes for several miles in

straight lines, several adjacent ones being parallel to each other. The dykes, however, and some of the larger masses are often more coarsely crystalline, and would be called greenstone rather than basalt. The metamorphic action of these dykes is well known. The chalk in contact with them is changed into a coarsely crystalline marble in some places, in others into a grey splintery limestone like much of the Carboniferous limestone. Some of the flints are reddened, and the soft greensand is turned into a hard red gritstone. (*See Catalogue of Rock Specimens*, in Museum of Irish Industry, Dublin.)

The basalt of the west of Scotland is likewise beautifully columnar, as at Fingall's Cave and other places, while that of Arthur's Seat is massive, and often crystalline, shewing distinct crystals of olivine, and being highly magnetic from the abundance of magnetic oxide of iron.

The ash associated with the basalt of the Calton Hill is very admirably exhibited on all sides of it.

The greenstone of Salisbury Crags has greatly altered and indurated the gritstone below it (one of the carboniferous sandstones) which is converted into a kind of quartz rock.*

It is probable that all these basalts and greenstones were of submarine formation, but the lower part of many lava streams proceeding from subærial volcanoes, or at all events from volcanoes which are now subaerial, are as regularly columnar basalt as the Giant's Causeway itself.

* Professor Edward Forbes had conceived the idea, which has lately been completely confirmed by Mr. Geikie of the Geological Survey, that the igneous rocks around Edinburgh belonged to two very different periods, the one part probably Carboniferous, and the other much more recent, probably Tertiary, perhaps contemporaneous with the Miocene (?) basalts of the north of Ireland and the west of Scotland. Mr. C. Maclaren had, however, anticipated Forbes in these conclusions. See *Mems. Geol. Surv.* Geology of country around Edinburgh, by Messrs. Howell and Geikie.

CHAPTER XIX.

VOLCANIC ROCKS.

Form and Mode of occurrence of Volcanic Rocks.—All volcanic masses formed in shallow water or on dry land, all those in fact which we are able to examine, assume a more or less perfect conical form. Beds of cinders and ashes varying from large blocks down to the finest and most impalpable powder, are deposited round a central orifice on slopes which are steepest nearest the orifice, and approach nearer to the horizontal as they recede from it. Streams of lava having issued from the central orifice, or broken out at some lower point in the sides of the pile, and sometimes broken one side of it down, spread wider and wider round its foot, or over the flat land about it.

When the original conical pile acquires a great size, lateral orifices or craters are formed about its flanks, and produce little secondary cones which often, as in Ætna, stud the sides of the main mountain in all directions with minor hills.

Sometimes a row of cones is formed along a certain line of country, without any central dominant cone, and sometimes two or more neighbouring cones grow to nearly equal mass, and are then buried under the accumulations of one of them, which either temporarily or permanently assumes the superiority.

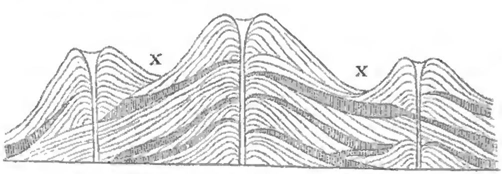


Fig. 99.
Ideal section through Volcanoes.

Fig 99 may be taken as a rough diagrammatic idea of the mode of formation of volcanic cones and craters, the parts marked by vertical

lines representing the lava flows, and the other lines the accumulation of beds of ash, including under that term all ejected matters except the lava flows. In reality, the structure will almost always be much more complicated, the minor cones and lateral vents being greatly more numerous, and the whole traversed in all directions by ramifying dykes and veins of lava, with lateral funnels or feeders for some of the lateral cones branching from the main vertical pipes.

The volcanic ejections are sometimes confined to one portion of a country, like Ætna in Sicily, where the volcanic rocks make a single gently swelling mountain, 30 miles wide at its base, and 10,960 feet high at its summit. In other cases, such as Java for instance, an island 600 miles long, numerous volcanoes become confluent in some parts so as to form continuous mountain ranges of 6000 or 8000 feet in height, and 30 miles in length, with craters in their higher and central parts, like the Bromo, and great symmetrical cones of 11,000 or 12,000 feet, as Semiru and Arjuno, rising at intervals from the main mass of the range. Smaller detached cones, such as Lamongan, rise from the adjacent plains with an elegant sweep, to heights of 3000 or 4000 feet. Java contains no fewer than thirty-eight volcanic cones of the first magnitude, the range being continued into Sumatra on the one side, with several cones of 11,000 or 12,000 feet, and through Bali, Lombock, and Sumbawa on the other hand, each with great volcanoes, that of Lombock being more than 11,000 feet* high. The volcanic chain, with many cones of equal or greater magnitude, runs from these islands northward, through those that fringe the eastern coast of Asia, and crossing into America, is continued down the whole of its western coast from Behring's Straits to Terra del Fuego.

The Asiatic volcanic islands, like those of the Atlantic, shew evident proofs of their having been elevated bodily since the volcanic action commenced, so as to exhibit a part of their old submarine roots, where the igneous are interstratified with sheets of aqueous rocks. The Andes of South, and the Cascade or coast ranges of North America, have been still further lifted up, so that their bases now form continuous dry land from Russian America on the north, down to the Archipelago of Tierra del Fuego on the south, in which latter part the bases of the mountains are still partially submerged.

When the volcanic activity finally ceases in any district, submergence may ensue, and if it be very slow and gradual, denudation will take place both during the submergence and during subsequent re-elevation, so that all the old conical piles of more or less loose and incoherent materials will be destroyed, and their materials ground down and swept far away to distant localities. Hence it is impossible that

* This altitude was determined by Mr. F. J. Evans, formerly of H.M.S. Fly, as she sailed under Captain Blackwood, through the Straits between Lombock and Sumbawa.

we should ever find volcanic cones preserved among the older rocks, where we have merely so much of the hard volcanic roots, or trappean rocks, as may not have been destroyed by denudation.

Lavas differ from traps partly in mineral character, such as the occurrence of augite instead of hornblende, and of labradorite or anorthite instead of orthoclase, etc., but principally in the texture and form of the rocks, rather than their composition.

True lavas have always been poured out either on the dry land, or in shallow water, forming regular flows or "coulées" of molten rock. Cooled under these circumstances, the upper surface of a lava stream is generally quite porous and vesicular from the escape of the gases pent up within. The upper portion of such a bed consists of loose blocks of cinders of all sizes, from rough masses of two or three feet in diameter, to those of as many inches. It has been likened to a mass of clinkers, slags, and cinders, from a huge foundry. The far end of a still flowing lava stream has been described as a slowly-moving mass of loose porous blocks, gradually rolling and tumbling over each other with a loud rattling noise, giving evidence of the pressure of a viscid mass of cooling lava within. The upper end of a lava stream, where it issues perfectly fluid from the intense heat of the volcanic orifice, moves much more rapidly.

All rock is a bad conductor of heat, so that, when once a lava stream acquires a cooled crust, the mass within may remain glowing hot for a considerable period of time. We are told of persons walking about on the cooled surface of a lava stream, while able to roast eggs or light cigars in the cracks and crevices of the crust. Caverns are sometimes formed in lava streams by the sudden escape of the molten mass below, leaving the cooled crust standing like the roof of a tunnel.

In such a mass, it is obvious that, while the upper surface was light, porous, and cindery, the lower portion, cooling much more slowly, and under pressure, might be solid, compact, or crystalline. As a matter of fact, wherever old lava streams have been cut into, either naturally or artificially, and their lower portions laid open to our inspection, we find the vesicular character of the upper surface gradually but rapidly disappearing below, and the rock passing quickly into a hard, compact stone, often columnar, and frequently quite crystalline.

The hornblendic or augitic lavas more readily assume the columnar form than the feldspathic lavas or trachytes, which, however, on the other hand, are often much more highly crystalline than the augitic dolerites or basalts.

The lower parts of many lava streams are not to be distinguished by any internal characters (and probably not by any differences in chemical composition) from columnar basalt.

Many old basalts, indeed, which are ordinarily considered as trap-

pean rocks, may have had a porous cindery upper surface at the time of their formation, that surface having been subsequently washed away by denudation.

Craters of Elevation.—Humboldt in his travels in New Spain gives a description of the volcanic mountain of Jorullo, and attributes its formation to the fact of the ground "having swollen up like a bladder." He derived his information apparently from the native inhabitants, who, even supposing their words to have been rightly understood, might readily have used such expressions without any strict warrant from the facts of the case.*

Von Buch seems to have taken from this description a notion that most volcanic cones and craters were thus formed, and to have allowed his mind to be so warped by this preconception, that in his subsequent observations he only perceived facts through its distorting medium. He also, together with Elie de Beaumont and Dufrenoy, adopted the curious notion that lava could not congeal and solidify on slopes greater than 4° or 5°. These novel ideas coming recommended by such high authorities were blindly accepted by many geologists even of the greatest reputation, and are by some British, and many foreign, geologists, even yet entertained. They have, however, been completely exploded by the recent publications of Sir C. Lyell, Mr. Poulett Scupe, and others, and if still retained by any persons, must be kept from habit and reverence for authority, and not from personal knowledge of facts. (*See Sir C. Lyell's Manual and Principles, and his Paper on the Structure of Lavas and Ætna, in Phil. Trans.*, vol. cxlviii., par. 2, and *Mr. Scupe's Papers, in Journal Geol. Soc.*, vol. xii., p. 326, *and* vol. xv., p. 505.

Peak of Teneriffe.—When I paid a hasty visit to the summit of the Peak of Teneriffe with Captain Blackwood, and some of the officers of H.M.S. Fly, in May 1842, I had no previous knowledge of volcanic districts, and had not paid any attention to the theory of elevation-craters. When, after ascending the mountain to the height of about 9000 feet, we rode across the plateau called the "pumice plains," towards the summit cone which rises from one corner of them, I could not fail of being struck by the circle of broken precipices surrounding the plateau. The ravines which cut through that surrounding wall shew the outer slope of the rude beds composing it, and the note I find in my journal respecting them, is the following:—"This plain is

* Every one who has been accustomed to glean information as to physical phenomena from persons not trained to observe them, or not having naturally great powers of exact observation, must be aware how vague and deceptive are the terms they frequently use. I have had geological facts described to me, even by educated men belonging to learned professions, in terms which subsequent observation shewed me to be ridiculously inapplicable, and sometimes conveying ideas the exact opposite of the truth.

bounded in some places by an entire wall of rock, in others, by broken and craggy hills, as if it had once been the interior of some enormous cone, of which these were only the ruined fragments."

On subsequently reading Von Buch's account of the Canary Islands, I was greatly surprised to find that he supposed this circular wall, with its outward sloping beds, to have acquired its height and position from a central action of elevation subsequent to the deposition of the beds. So far as I had observed there was no warrant for such a supposition. It was clear, indeed, that the whole island had been elevated since the volcanic action had commenced, because I had seen in the sides of a ravine near Santa Cruz, horizontally and regularly stratified beds of volcanic sand, and pebbles that seemed certainly to have been arranged under water (see plate xii. in *Popular Physical Geology*), but then these beds remained horizontal, proving the elevation to have been a general one, lifting the whole sea bottom without tilting the beds in any direction.

Island of St. Paul.—We subsequently visited the little volcanic island of St. Paul's, in the centre of the South Indian Ocean, of which a chart constructed by Mr. Evans, Master of the Fly, was afterwards published by the Admiralty. This island is three or four miles across, with a flat topped curved ridge, 820 feet high, nearly surrounding a circular crater into which the sea now flows from one side, and which, at the sea level, is almost half a mile in diameter. From the summit of the circular ridge the island slopes gently down towards the sea on all sides except the east, where there are vertical cliffs formed by the sea having cut into the centre of the original island, so as to gain access to the centre. On the south side of the entrance, the wall bounding the crater was excessively thin, vertical on the outside, and sloping steeply on the inside, so that it must shortly be removed entirely, and all that side of the crater laid open to the sea. The entrance was not more than 100 yards wide, and only just deep enough for a boat, but inside there was a depth of 30 fathoms in the centre of the crater, with a bottom of black mud. This funnel-shaped pool was surrounded on all sides but one by the ring of high land before mentioned, the inside slope of which was precipitous near the top, but had a steep talus of rubbish clothed with coarse grass below. At several parts of the beach, hot smoking water trickled through the stones, having at one place a temperature of 138° F., and at another, one of 150° F., while the temperature of the water in the crater, both at the surface and at the bottom, was precisely that of the sea outside, namely 54° F. (This was on August 5th, 1842.) A bank of soundings stretched off the eastern side of the island for a distance of nearly a mile, and a tall detached pinnacle of rock rose from this near the entrance to the crater. This bank was evidently the base from which the rocks that once sur-

rounded the crater, and completed the island on this side, had been removed, all except the pinnacle above mentioned.

The island seemed wholly composed of dark lava in irregular beds, with beds of sand, ashes, and blocks, varying from black to red and cream-coloured. They dipped but slightly outwards, and at one part seemed to dip inwards or towards the crater.

Another volcanic island, called Amsterdam, rises some 60 miles to the north of St. Paul's, these being the only spots of land in these latitudes between Africa and Australia.

Crater of the Bromo.—In November 1844 I had an opportunity of visiting the crater of the Bromo in Java. This is in the centre of a rugged and broken mountain range called the Teng'ir, rising in some parts to upwards of 8000 feet above the sea, and stretching, as before mentioned, in a curved line between the noble cones of the Semiru and Arjuno, so as to include the beautiful valley of Malang in a semicircular sweep. This mountain mass is all volcanic, greatly covered externally by fine-grained dust and ashes, enclosing, however, solid crystalline lava rocks below. Its sides are furrowed in every direction by ravines with narrow ridges between them, the whole clothed with magnificent forests; tall pine-like casuarinas cresting the ridges up to a height of 6000 or 7000 feet.

In about the central part of this range, on the summit of its most massive part, is a crater four or five miles wide surrounded by a ring of precipices varying from 200 to 1200 feet high. In the centre of this great crater rises a rude cone studded all over with minor cones, some of the craters of which are continually belching out smoke and steam, and sometimes ashes and hot stones. Others are covered with wood, and the sides of this conical mass are furrowed with ravines like the external slopes of the mountain, except in those parts where the ejected ashes have been quite recently deposited. The space between the foot of this smaller central conical mass and the surrounding precipitous wall is often more than a mile in width and is covered with fine sand and known by the name of the "Laut pasir" or sandy sea. The surrounding wall seemed quite unbroken, for we had to ride round the summit of half of one side of it by a narrow and giddy path, in order to take advantage of a sort of buttress-like ridge, apparently made of fallen fragments, to gain access to the interior, and on the other side the path at two places led by sharp zigzags up the side of the precipice. These paths seemed to be the only modes of communication between the villages on the outside of the mountains, some of which are places of great resort.

Horizontal-looking beds of hard trachytic, sometimes porphyritic, lava were visible in the face of the surrounding precipice, which, how-

ever, though they looked horizontal when viewed from the interior, might have easily dipped outside down the mountain.

It seemed to me perfectly impossible that such a crater as the one I have here described could be formed by an action of central elevation. On the other hand, looking at the grand cone of Semiru, which rose a few miles to the south-west, it was obvious that it only required the upper 3000 feet of that lofty pile to be removed, either blown into the air, or undermined and engulphed in the central cavity of the mountain, for an exact repetition of the Bromo to be produced.

I fully believe, therefore, from all I have read or have myself observed, that the crater-elevation hypothesis is entirely unsupported by fact, and even more than that, for I have lately seen reason to doubt the physical possibility of its occurrence, as will appear in the ensuing chapter.

Dykes and Veins of Lava.—Just as among the trap rocks we found dykes and veins frequent, seeming sometimes to be the mere extensions of the mass below into the cracks and crevices of the rocks above or around it, sometimes apparently the feeders of overlying masses, so we find volcanic cones and the surrounding districts penetrated in every direction by dykes and veins of compact lava, serving often to bind together or to support the otherwise rather incoherent materials; and we must be aware, although we cannot see it, that every lava stream has its central pipe or feeder in the interior of the mass from which it proceeds. It is probable that, both in the case of traps and lavas, the size of the feeders often bears but a small proportion to the mass of the overlying rocks that proceeded from them.

It is not absolutely necessary, in the case of a volcanic cone, that the flow of lava and the central pipe or feeder should remain in connection, and cool and consolidate together; for when the lava ceased to be impelled so as to flow over the crater, the portion left in the funnel might sink down and perhaps ultimately cool and consolidate at a considerable distance below, and might possibly make even a different kind of rock from the ejected mass.

This may sometimes occur also among trap rocks, since it is quite easy to conceive that an overlying mass or an injected bed might be deserted by its feeder on the internal impelling power being withdrawn, and the orifice by which it rose might be closed, so that two masses of rock may be formed at different places, and possibly of rather different character, though once perhaps actually forming part of the same molten mass.

Lyell describes the numerous dykes which traverse the sides of the great valley scooped out of one side of Etna, called the Val del Bove, and numerous instances are figured by Walterhausen in his magnificent work on Etna, of dykes of lava traversing beds of turf and ash, both

vertically and horizontally, the latter being often shewn to have been intruded dykes by their bifurcation.

Every volcanic district which has been laid open by denudation exhibits similar facts. The cliffs, for instance, along the south coast of Madeira, west of Funchal, expose numerous dykes traversing the beds of tuff exposed therein. The following figures, 100 and 101, were

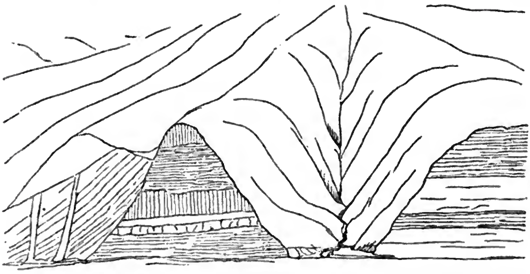


Fig. 100.
Sketch of the cliffs near Calheta.

sketched from the deck of H. M. S. Fly, as we sailed close in along this coast in April 1842. Fig. 100 exhibits in one cliff portions of beds of lava, some of them columnar, interstratified with tabular laminated beds,

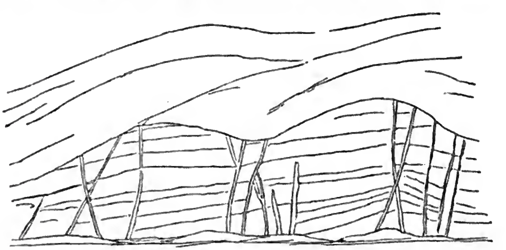


Fig. 101.
From a sketch a few miles west of Funchal point.

against the denuded edges of which pale cream-coloured beds had been deposited in an inclined position, as shewn in the left hand corner of

the sketch, with two gray dykes cutting across these beds. Fig. 101 shews several veins or dykes of a hard gray lava rock cutting through rudely stratified, coarse, incoherent-looking materials of a dull red colour, some of the dykes being also cut by similar ones of more recent date.

Association of Trachytes and Dolerites.—In many volcanic regions there appears to be an alternation, or to have been a succession, in the different products; the lavas being at one time trachyte, and at another dolerite. It seems at one time to have been supposed that the trachyte was always the lower or the older of the two, and that flows of trachyte were never found above flows of basalt or dolerite. Lyell, however, has shewn that some of the newest lavas in Madeira are trachytic, while they cover others consisting of doleritic compounds.

Bunsen, in a paper formerly cited (Sc. Memoirs), in speaking of the trachytic and augitic lavas of Iceland, refers their origin to two separate volcanic foci, and even speaks of a third separate volcanic focus for the intermediate lavas, though he also speaks favourably in another place of all the volcanic rocks arising from one mass.

Durocher, too, in his essay on Comparative Petrology, refers the two classes of igneous rocks of all kinds, namely, the siliceous and the basic, to the existence of two separate "magmas" below the crust of the earth, the siliceous or lighter floating over the basic or heavier, and ejection taking place from one or the other according to the strength of the impelling force; the ejection of the lighter therefore generally preceding that of the heavier.

The identity or very great similarity of the various volcanic products in all parts of the world, seems to point to a common origin for them. The frequent association in all parts of the earth of the two great classes of these products, the trachytic or purely feldspathic (or highly siliceous, with little alkali, lime, or iron), and those in which the feldspathic are largely mingled with hornblendic or augitic minerals (containing much alkali, lime, or iron), seems to me to shew that their separation is not so much due to diversity of origin, as to some cause tending to segregate the one from the other, out of a generally diffused mass, in which the constituents of both may be equally mingled.

The association previously mentioned of felstone and greenstone among the traps seems to be reproduced in that of trachyte and dolerite among the lavas. In both instances the occurrence of pure or unmixed feldspathic rocks is less frequent than that of those in which the feldspar is mingled with the more basic minerals, although when the purely feldspathic rocks do occur they form generally larger masses than the basic ones. Trachytes and felstones seem both to be confined to certain localities, in which, however, they are very abundant, sometimes alone, and sometimes largely mingled with dolerites, basalts, or greenstones. These latter rocks, on the contrary, are not only found

in association with the former, almost wherever these igneous rocks appear, but also in many other districts, in large or small quantities, unaccompanied by any other igneous rocks.

If we assume all igneous rocks to proceed either from one central molten mass of equable constitution throughout, or from separately fused portions of perfectly similar constitution, might we not suppose that the difference in the constitution of the various products which we find at the surface depended on the circumstances and conditions in which they had been placed? The portions now open to our examination had probably to pass through different thicknesses and different kinds of other rocks; they would be placed then under different conditions of temperature and pressure, which might perhaps alone cause a separation to take place in their different ingredients; they might also take up in their passage other ingredients of different character from those which they originally possessed, or larger proportions of one or other of their original ingredients. In those places or at those times when violent accessions of heat approached most nearly to the surface, trachytes and felstones might be poured out, while at other periods, when the heat was less intense, no molten rock could reach the surface unless it were composed of more easily fusible minerals. These more readily fusible substances might be conceived either to have separated in liquid strings and veins from the consolidating rocks below, or to have been acquired by the upper portion of the mass from the rocks it met with in its passage towards the surface, the substances thus added having acted as an additional flux to matter which would otherwise have solidified before it could have been poured out.

Some such hypothesis as this seems to me less forced than one which obliges us to suppose separate deep-seated foci or reservoirs for every variety of igneous rock, those varieties frequently occurring in the same district, and alternating one with the other over the same space of ground.

If it be well founded, it will enable us to account for the gradual changes in one connected igneous mass, as also for the veins and patches of different character sometimes to be found occurring very abruptly in such masses, independently of the supposition of a subsequent intrusion of one igneous rock through the body of another. This would often relieve us of a difficulty where the veins are confined to the igneous rock and do not penetrate the adjacent aqueous rocks. We might then look upon such veins as veins of segregation, occurring probably at the time of the contraction consequent upon the mass of the rock passing from a molten to a solid state, or from a pasty to a crystalline state (see *ante*, p. 96), while yet some parts of it remained fluid.

Exciting Causes of Volcanic Eruptions.—Sir H. Davy suggested that volcanic eruptions might be caused by the oxidisation of the

metallic bases of earths and alkalies. If repositories of these substances exist in the interior of the earth, and especially if they have already a high temperature derived from the earth's internal heat, and if oxygen either of the air or of water be brought into contact with them, the phenomena of volcanic action might be produced by the local intensity of the heat thereby generated. Dr. Daubeny looks on this explanation as perhaps the most probable one—(see chapters xxxvi. et seq. of Daubeny's work on Volcanoes),—and shews that whether the earth have an intense internal temperature or not, in other words, whether or no the observed internal temperature lead to the conclusion of "central heat," the local action of volcanoes may be due to the oxygenation of metallic bases.

Few authorities, however, excepting Dr. Daubeny, now regard this chemical explanation of volcanic activity as sufficient.

Bischof, taking for granted that the observed internal temperature of the earth increases towards the interior at the same rate as near the surface, attributes volcanic activity to the mechanical action of water gaining access to the heated interior, and being there converted into explosive steam.

He supposes the fusing point of lava in general to be about 2282° F. —a temperature that would, he says, be attained at a depth of about 113,500 feet below Geneva, the Erzgebirge or Cornwall, and at 126,800 feet beneath Vesuvius and Etna.

He remarks that the elastic force of steam is at a maximum when it has the same density as water, and that it would acquire that density under the pressure of 8300 atmospheres, or at a depth where the temperature would be 2786° F., or 500° F. more than necessary to fuse lava. But supposing the mean specific gravity of lava to be 3, the loftiest column of lava which could be supported by steam at its maximum density would be 88,747 feet, or much too little to reach the surface in Germany or Cornwall, and still more deficient for that of Italy. He says, however, that this difficulty may be got over by supposing the column to be made of lengths of steam included between lengths of molten lava, like bubbles of air in the mercury of a barometer, a supposition rendered probable by the frequent alternations of outbursts of lava and vapour during an eruption.

The hypothesis, however, seems to involve the idea of columns of water, and columns of lava, or of lava and steam, having equal access to the heated interior, and the ejection of the lava column rather than that of water. Bischof discusses this objection, and observes, that supposing the waters of the sea to gain access, by means of fissures, to depths of 113,000 or 126,000 feet, where the temperature would be 2282° F., that the elastic force of steam there would be equal to the pressure of 5310 atmospheres, while the hydrostatic pressure would be only equal to

3547 atmospheres in the first, and 3963 atmospheres in the second case ; so that these columns would be quite unable to resist the pressure of the steam, and would be themselves ejected instead of the lava.

He observes, however, that the elastic force of the steam would decrease more rapidly in consequence of decrease of temperature than would the hydrostatic pressure, and that consequently there must be some depth where the two would balance each other ; and on the supposition of the temperature decreasing towards the surface at the rate of 1° F. for every 51 feet, he calculates that this point of equilibrium would be at a depth of 88,044 feet below the level of the sea, where the temperature would be 1754° F. He arrives at the conclusion that columns of lava, from 29,348 feet to 35,209 feet in altitude might be lifted by steam from depths of 88,044 feet and 105,627 feet respectively, provided the communications between the sea and the volcanic focus were not interrupted.*

As long as these communications were open the volcano could have no perfect rest, although the formation or arrival of fresh lava in the base of the funnel might necessitate an intermission in its eruption.

The channels of communication between the volcanic focus and the sea might be interrupted either by lava itself being forced into them, or by the fusion and soldering together of their walls, or by other circumstances, and the eruption would then be interrupted or cease till the channels were opened again by a shock, or by the expansion of their walls, or by some other action. The more the lava below was cooled by the water or by the formation of steam, the longer would be the time required for its remelting, especially as lava is a bad conductor of heat.

The alternations of repose and activity, then, in a volcanic vent are those of the solidification and remelting of the lava below, and the interruptions and reopening of the channels between the water and the volcanic focus.

It will be seen that both the chemical and mechanical explanations offered above require a communication to be established between the interior of the crust of the earth and its surface, especially that part of it covered by water. Inspection of any maps of volcanoes will shew that all the great active volcanoes are either in islands or not far removed from the borders of the sea.

* Some recent experiments have shewn that water will readily pass through porous substances which are quite impermeable to it when converted into steam, so that it is possible to conceive pent-up reservoirs of steam receiving continued accessions from water arriving by channels which the steam cannot escape by.

CHAPTER XX.

OROGRAPHY, OR THE STRUCTURE AND ORIGIN OF MOUNTAINS.

Relations between the intrusion of Igneous Rock, and the elevation of Stratified Rocks.—Mr. Darwin in his book on Coral Reefs points out that atolls and barriers, forms which, as we have already seen, are a consequence of the depression of land beneath the sea, are never found in the same areas with active volcanoes; and that active volcanic islands have only fringing reefs around them. I observed myself, when visiting some of the islands belonging to the volcanic band of the eastern archipelago, namely, Timor and Java, and sailing along the islands between them, that part of their lower grounds consisted of raised coral reefs, the old fringing reefs which had surrounded the islands when they stood at a lower level.

Many other volcanic islands exhibit proofs of the elevation of the old sea bottoms, on which some of the earlier lava streams had been poured out, since those lava streams alternate with aqueous rocks, deposited on their cooled surfaces during the intervals of eruption.

Those of Sicily and Madeira are mentioned by Lyell, those of the Canary islands were described by Von Buch, those of St. Helena and others, by Darwin, and we may perhaps be almost warranted in saying that all volcanic islands have risen or are rising from the sea, not only in consequence of the accumulation of ejected volcanic materials round their orifices, but because of the raising of the base on which they stand.

We may even extend this assertion to other volcanic chains, such as the Andes, the old submarine base of which is now continuous dry land, as before mentioned.

These facts shew a connection between the elevation of parts of the earth's crust, and the intrusion and ejection of igneous rock from its interior towards its surface, a relation which seems also to have existed with respect to the irruption of the trappean and granitic rocks, as well as the eruption of the volcanic.

It would not, however, be a correct representation of the facts to say that the irruption or eruption of the igneous rocks had been the cause of the elevation of the surrounding ground. The two phenomena seem to be the simultaneous effects of the same cause rather than one

the cause of the other. That cause may be described as the disturbing action of great internal heat, to which some agent or other had imparted a local excitement and determination towards the surface. This heat acting against the inner part of the crust of the earth, tends both to make it bulge outwards and to break through it, and where it does break through it the molten rocks below are often forced into the fissures, and sometimes through them, so as to boil over on to the surface.

In this view of the matter we should expect the elevation of aqueous or older igneous rock to precede rather than follow the intrusion of fresh igneous materials, and that the irruption or eruption of the latter would afford a local or temporary relief to the movement of elevation.

The injection of igneous rocks into the cracks and fissures formed during elevation, and their subsequent consolidation there, would doubtless be efficient to prevent or lessen the depression consequent on the withdrawal of the expansive force of heat.

The occurrence, however, of igneous rocks in any part of a disturbed district is accidental, since it must depend on the place where cracks and fissures were produced, and on their form and position being such as to allow of their being filled with the molten matter.

When speaking of faults and contortions, it was observed, p. 262, that the two occur rather in different parts of a disturbed district than together. The disturbing forces either bend the rocks or break them. If the rocks are fractured, the fragments may be moved up or down without being bent; if, however, they are not broken through, motion can take place by bending only.

The fractures may take place either where the greatest force is exerted, or where the least resistance is opposed to it, the strain on the adjacent parts being in either case relieved by the fracture.

Observed fact, as far as my own experience goes, certainly is in harmony with these *à priori* considerations.

It has been already remarked that even large granitic masses do not occur as axes or centres of elevation in the way in which they were at one time supposed.

Examination of the accurate geological maps published of late years by the Geological Surveys of European and American states, as well as those of our own country and colonies, completely confirm this statement.

Trappean rocks also are in no instance that I am acquainted with, the centres or axes of elevated districts. On the contrary, the occurrence of intrusive trap seems, in many cases, to have relieved the action of the disturbing force and moderated its effects. In other cases, the traps, both intrusive and contemporaneous, have been bent or

broken by the disturbing forces just exactly as much as the aqueous rocks with which they were associated, proving that the occurrence of the igneous rock was not the cause of the disturbing effect, but that the disturbance was altogether of subsequent origin, and was not accompanied by the intrusion of igneous rock.

Volcanic islands and districts, even those that have been most elevated, exhibit precisely similar facts. The elevated beds formed beneath the sea, which were just now spoken of, almost always retain the horizontality which they originally possessed.

This seems to be the case in Sicily from Lyell's descriptions; it is certainly the case in one part of Teneriffe, and was also the case in Java and Timor, and in those parts of the intermediate islands I was able to observe. It is also true of St. Jago, one of the Cape de Verde Islands, according to Darwin (see his *Volcanic Islands*).

They all seem to have been raised bodily by an upward swelling of a broad area bearing the volcanoes on its back, and in no case can it be shewn that the volcanic orifices have acted as centres or axes of elevation to those beds around them which were undoubtedly formed beneath the sea.

Even where the beds in volcanic islands, such as St. Helena, or in great volcanic chains, such as the Andes, have been greatly disturbed, and tilted in various directions (as described by Darwin in his *Volcanic Island and South America*, and lately by Mr. D. Forbes in *Quarterly Journal Geol. Soc.*, vol. xvii., part 1), those directions are not at all governed by the position of volcanic orifices.

In St. Helena the beds of volcanic materials seem to have been thrown into various inclined positions, dipping both from and towards what was probably the central orifice during the time of eruption.

In the Andes both older igneous and aqueous rocks appear to have been violently disturbed and thrown into many anticlinal and synclinal flexures, the axes of which doubtless run parallel to the direction of the chain along which the volcanic orifices are ranged; but the beds appear to be just as much disturbed where there are no volcanoes as where they exist, if indeed they are not more disturbed in the parts from which volcanoes are absent.

I believe, then, that we are perfectly warranted in making the general statement, that there is no direct relation between the *lines or points of irruption or eruption* of igneous rock of any kind, and the inclined positions of the surrounding beds of aqueous rock; in other words, that igneous rocks do not, except accidentally, form the centres or axes of the elevations which have affected the crust of the earth.

If this assertion be generally true, it will follow that it is exceedingly improbable that cones or craters could be generally formed by elevation round volcanic orifices.

Steep Inclinations never communicated to Beds by disturbance acting near the Surface.—Recent reflection, indeed, has led me to doubt the physical possibility of the formation of a conical mountain by any local action of upheaval anywhere *at the surface of the earth.*

Every one who has examined any much disturbed district must of course be familiar with the fact of the dome-shaped elevation and basin-shaped depression of rock beds, with a quaquaversal dip from or towards a central spot. Some of these, when their sides are but slightly inclined, or when their base is large in proportion to their height, are very symmetrical; when, however, their sides approach in steepness to those of a volcanic cone, they are rarely, if ever, so symmetrical as the majority of volcanic cones. Their forms become oval or irregular, or their beds are much more highly inclined in one part than another, or they are broken by dislocations that destroy the symmetry of their shape.

There are hardly perhaps anywhere to be found dome-shaped elevations of beds of aqueous rock that more nearly approximate in form to what we might suppose denuded volcanic cones would assume on the *crater elevation* theory, than the three quasi dome-shaped elevations of Wenlock Limestone just north of Dudley, known as the Castle Hill, the Wren's Nest, and Hurst Hill, ranged as they are in a straight line, and with the beds of each dipping in all directions from their central parts. Nobody, however, could look at the geological map (62 south-west of the maps of the Geological Survey, or the sketch on p. 146 of the *Geology of the South Staffordshire Coalfield*) without perceiving how much they differed in form from that of any volcano, independently of the absence of a crater.

If, however, volcanic cones and craters are formed by elevation round a central point, there seems no reason why other rocks that have been similarly elevated should not have exactly similar forms, even if they have not craters formed in them.

There are even many craters known, such as the Creux de Morel in Auvergne, the Pulver Maar, and other Maars in the Eifel, round which very small accumulations of volcanic ejection have taken place, and yet no quaquaversal inclination of the aqueous rocks around them is to be seen. They seem mere holes drilled through the rocks, without any tilting of their sides.

Even, however, if we disregard the differences in form observable between volcanic cones and quaquaversal elevations of other rocks, there remains another most essential distinction to be pointed out.

No highly inclined beds, whatever may be the shape they have assumed, can anywhere be shewn to have acquired their high inclination at or near to the present surface of the ground. No dip of even 30° in any aqueous rock whatever, and continued for more than a few yards, can be proved to have been acquired at the surface, or rather no

such dip can be pointed out anywhere in the world, that cannot be proved to have existed before the production of the present surface of the ground by denudation. This assertion is made partly as the result of rather widely spread personal observation and a tolerably extensive examination of the observations of others, and partly from *à priori* considerations.

If horizontal beds with a horizontal ground surface be tilted into an angle of 30°, it follows that the surface of the ground must have an equal inclination. But a ground surface slope of 30° never occurs for more than a few yards, except in hilly or mountainous regions, which can always be shewn to have suffered greatly from denudation, and where the slope of the beds and that of the surface rarely coincide in angle and direction, except accidentally and for small distances.

Wherever beds are highly inclined, it can always be shewn that great denudation has taken place there, otherwise the ground-surface must precisely follow and agree, both in inclination and altitude, with the lie and extent of the beds.

In such cases as the vertical Chalk running through the Isle of Wight, it only requires inspection of the map (sheet 9) and sections (No. 47) published by the Geological Survey, or the smaller ones given in the Memoir on the District by Professor Edward Forbes and Mr. Bristow, to be convinced that the whole of the Eocene rocks at least, which are more than 2000 feet thick, have been removed since the Chalk beds acquired that high inclination.

Among older and more greatly disturbed rocks, where alone in Britain we have steep-sided quaquaversal inclinations, the subsequent denudation can always be shewn to have been enormous.

It was from want of allowing for this denudation that the mistake naturally arose of attributing the production of such disturbances to forces of greater intensity than any now acting on the earth. It has been said rightly enough, that no such disturbances and tiltings of beds as may be often seen at the surface are ever now produced anywhere at the surface of the earth, but the fact was ignored that the very effects referred to were not themselves produced at the surface.

If the reader will turn to p. 237 *et seq.*, and the figures of contorted and denuded beds there given, he will see at once the gist of these remarks.

It is doubtless true that the force required to bend solid rock, and tilt it into such positions, must have been one of greater intensity than any we have experience of at the surface, but it is equally true that a force acting with such local intensity never could have reached the surface. All forces of disturbance acting on the crust of the earth must proceed from the interior, and must travel through the whole thickness of the crust before they can reach its upper surface. Before, then, they

reach that surface, their intensity must be weakened so much by dispersion in the mass of that crust that their effect at any particular locality of that upper surface will be but a fraction of that with which they acted on points of what we may call the under surface of the earth's crust.

In order that any locally intense movement should take place in that crust such as would produce high inclination of beds, an immense accumulation of force must be brought to bear upon a comparatively small internal part of it. The result will be that some weaker line or point will first yield, and the disturbance there will, to a certain extent, relieve the pressure on other parts. Lines or points that have once yielded will be apt to yield again on a recurrence of the accumulated force, elevation of one part may produce depression of another, and we may conceive any amount of bending, or any amount of fracture, in the immediate neighbourhood of the local centres of intensity of action thus generated.

But before the disturbance arising about these could reach the surface it must, as just now said, be so dispersed on all sides through the thickness of the crust, that its local energy must be lost, and the effect produced at any point of the surface must be comparatively slight.

It is difficult to imagine any cause that could gather these rays of disturbing force together again, and so *focus* them on any point of the surface as to produce great local disturbance there.

We only become aware of the local agency of the deep-seated forces of disturbance when we have the once deeply-seated rocks brought up from their depth, and exposed at the surface by the action of denudation.

It has been already observed that the very fact of the occurrence of a fissure producing a connection between the surface and the deep-seated parts of the earth, where molten rock exists, will relieve the energy of the uplifting force, while the outpouring of that molten rock must rather tend to produce a cavity into which some of the adjacent rocks may sink.

This seems sometimes to have been the case with volcanoes, as in the section in the neighbourhood of Porto Praya, given by Mr. Darwin in his *Volcanic Islands*, and I have seen reason to suspect a similar action to have occurred in cases of the eruption or irruption (whichever it may have been) of trap rocks, as in the South Staffordshire coalfield, and the irruption of granite, as in that of the south-east of Ireland.

The movement of molten rock may in this way be sometimes a cause of the motion of the rocks above or about it, but if so, it will be a movement of depression in the part from beneath which molten rock came, and not of uptilting in the rocks over it. Moreover, the inclination will be that of dip towards rather than from the intrusive mass.

Mountains are of three kinds.—From what has been said in this

and preceding chapters, it will be seen that hills and mountains are of three kinds.

a, *Mountains or Hills of Circumdenudation* (see p. 282) produced by the removal of the surrounding rocks, in which the base of the mountains and the adjacent plains are formed of the same, or nearly the same, set of rocks, whether they be horizontal or gently undulating. (See fig. 71.) It not unfrequently happens that the beds beneath the hill have a quaquaversal dip inward, as in the hill in fig. 71, so that the beds form a basin, while the surface of the ground is a hill.

b, *Mountains of Uptilting* (see fig. 72, p. 282), in which lower beds have been reared up in the central parts, while the circumjacent lowlands are formed of rocks much higher in the series than those forming the hills. Although in this case the amount of denudation has actually been greater on the mountains than on the adjacent low grounds, it has not succeeded in wearing them down to the level of the plains, because its levelling action has been more than compensated by the up-pushing agency of the internal elevating force.

c, *Mountains of Ejection*, of which volcanoes are the only examples, caused by the piling of materials ejected round central orifices, as in fig. 99, p. 332.

Mountains, then, formed simply by the elevation or uptilting of previously existing rock, and unaccompanied by denudation, whether they be volcanic cones, or formed of other rocks, have, as I believe, no real existence, and are so highly improbable, that we may feel justified in asserting that they are physically impossible.

Valleys are of one kind only.—Valleys are in all cases the result of the erosion of rock that has been lifted above the sea, whether that erosion has acted along the summits of anticlinal curves or along the bottoms of synclinal curves, or has cut through the rocks, as it has in the majority of instances, without paying any regard to the position and lie of their beds. There is no such thing in nature as a valley of elevation, or a valley of depression, if by that term we understand one formed without denudation, or as a direct consequence of the tilting of the beds over an anticlinal or under a synclinal axis.

Intercolline Spaces.—The only hollows between hills that were not produced by denudation are those between volcanic mountains, such valleys being a consequence of the growth of the mountains around them, in the way already alluded to. In fig. 99, p. 332, the spaces marked x x will give an idea of the mode of formation of such valleys. For such Sir C. Lyell has lately proposed the distinctive term "intercolline spaces," in order to distinguish them from valleys proper, which are always excavated by denudation, cutting into previously existing rock, and to shew that they appear like valleys solely in consequence of the growth of the surrounding hills.

E. De Beaumont's Theory of the Parallelism of Mountain Chains.—Whoever examines the structure of a great mountain chain such as the Andes or the Alps, or such as the lesser mountainous hills of the British Islands, will see that the beds of which they are composed have been thrown into several bold corrugations or long folds, the axes of which run more or less strictly parallel* to each other.

It often happens, too, that neighbouring mountain chains, such for instance as the Swiss Alps and the Jura, are parallel to each other. This is the case also in North Wales with the mountains of Cærnarvonshire, and those of Merioneth, which run north-east and south-west; it is the case in the south of Ireland with the Commeragh, the Knock-mealdowns, the Galtees and the Kerry mountains, which run nearly east and west (or east by north, and west by south), and similar parallelism may be observed in Scotland, and in fact in all parts of the world.

This parallelism in neighbouring mountain chains is merely an extension of the parallelism that may be observed in the anticlinal and synclinal curves, in the cleavage and foliation, and in the faults and dislocations of a district. The areas over which this parallelism extends vary greatly in extent, and often include smaller areas in which great departures from the general parallelism may be observed, those small areas being often smaller districts in which the direction of the widely acting forces has been modified so as to produce another local parallelism with a different bearing from that by which it is surrounded.

There are also very commonly cases in which the direction of all these lines changes gradually, so as to run along a very different bearing in one part of their course from what they do at another. In the case of the Jura, for instance, the strike of the beds and of the ranges near its southern termination is almost north and south, in the centre it is north-east and south-west, while at the other extremity it is nearly east and west.

In parts of north Wales the very same beds gradually curve round from the general north-east and south-west strike, so as to run due east and west, as may be seen by walking along the crest of the Berwyn

* The longitudinal valleys accompanying mountain chains often run parallel to these folds, not because they have been produced by them, but because when the denuding force succeeded in wearing down the ground to near its present surface, the different folds brought harder or softer rocks within its influence.

The straight valley of the Rhone above Martigny, and the valley of Chamounix, which runs in the same line, have both been excavated along some black shale or slate which was rolled in between the harder semicrystalline rocks of the Bernese Oberland, and the Brevent on the north-west, and the range of Mont Blanc and Monte Rosa on the south-east. These black slates may be seen at the head of the Rhone valley, in the hills immediately west of Martigny, and about the ridge of the Col de Balme, and again at the south-west end of the Chamounix valley. These valleys are in the central line of the Alps, and might be called the axis of the chain, as the knot of the Furca from which the Rhine and the Rhone and all the great rivers spring, is certainly the central knot of the Alps.

range from the part east of Bala Lake to that lying south of Llangollen. The several parts of a mountain chain, then, which lie beside each other are generally parallel to each other, and neighbouring mountain chains are similarly parallel for certain portions of their length ; but the bearing of one portion of the length of a mountain chain is by no means parallel to its bearing in another portion, and neighbouring mountain chains often include exceptional areas, sometimes of considerable size, in which there is great departure from the general parallelism.

Now it can generally be shewn that the elevation of a mountain chain was the result of a widely-spread force, the maximum effects of which took place in a certain given direction over considerable areas, and that therefore these parallel parts of the mountain chain were simultaneously tilted.

It commonly happens, too, that all the synclinal and anticlinal curves, and therefore the strike of the beds, the main faults and the cleavage (all being the different results of the same mechanical force) run parallel to each other, and were produced, or at all events commenced simultaneously.

It will be exceedingly likely also that, when once the direction of these structures is communicated to any area, any subsequent disturbing force will act along them. The features being once sketched out, a repetition of the process will be more likely to deepen and heighten them than obliterate them.

Struck with this relation between the parallelism and synchronism, M. E. de Beaumont passed to the bold generalization that all mountain chains all over the world that are parallel to each other were formed contemporaneously.

But when we extend the idea of parallelism from a part of the earth's surface that can be considered as a plain to the whole curved superficies of the spheroid, there arises a difficulty as to what we mean by parallelism.

Lines running east and west right round the globe, or parallels of latitude, are strictly parallel to each other, or will always be at the same distance from each other. Lines running north and south, however, or meridians, meet at the poles, and therefore cannot be parallel to each other. And lines running round the globe, and crossing the parallels of latitude obliquely, change their compass bearing continually. The ecliptic, for instance, as marked on the terrestrial globe, runs from the equator into the northern hemisphere along an E.N.E., bearing, changes that at the tropics to one nearly east and west, and ultimately to the south of east, passes into the southern hemisphere as an E.S.E line, coincides gradually with the southern tropic as an east and west line, and then gradually returns to its former bearing.

If we draw short lines on a globe of glass, on all sides of it, all of

them running north-west and south-east, or inclined to the meridians of the different parts at a constant angle of 45°, and then held up the globe and looked through it, we should see those lines crossing each other at all kinds of angles, and those at the antipodes of each other would be at right angles to each other.

Mountain chains, then, which run north-east and south-west, or in any other given direction, in different parts of the globe, are any thing but parallel to each other.

M. E. de Beaumont, therefore, defines what he means by parallel mountain chains, by stating that they are those which are arranged along small circles parallel to the same great circle: just as all the parallels of latitude are small circles parallel to the great circle called the equator.

If we take an orange, and cut it in any direction by a clean slice right through the middle into two equal halves, but do not allow the halves to separate, the line traced on the outside of the orange represents a great circle. If we then cut it into smaller slices, by cuts which are strictly parallel to the first, still keeping the pieces unmoved, the lines traced by these cuts on the surface of the orange represent small circles parallel to the first great circle.

M. E. de Beaumont afterwards shews that the mountain chains of the globe thus classified can also be grouped, so that their directions shall form a pentagonal network, and spends, according to Mr. W. Hopkins, a wonderful amount of ingenious and profound mathematics in tracing out their geometrical relations. (See Mr. W. Hopkins's Presidential Address, *Quarterly Journ. Geol. Soc.*, vol. ix.)

For purposes of comparison he selects three centres, to which the different lines of direction are referred, and finds a certain approximate agreement among them. It is unnecessary to go into the discussion of the theory at greater length, since, when thus extended and transcendentalized, it obviously ceases to have any practical value. As, however, the student may wish to know what were the ultimate results arrived at, I add the table of the systems given in Mr. Hopkins's address, in which the centre, to which the bearings of the lines were referred, was Bingerloch on the Rhine :—

System.	Orientations reduced to Bingerloch.	Regions in which Systems exist.
I. Vendée	N. 14° 52′ W.	La Vendée, Brittany.
II. Finisterre	E. 12° 21′ N.	Brittany, Normandy, Sweden, Finland.
III. Longmynd	N. 31° 15′ E.	The Longmynd, Brittany, Normandy, Saxony, Sweden, Finland.
IV. Morbihan. Lower Silurian, Upper Silurian, Tilestone.	W. 45° 38′ N.	Brittany, possibly in many other places.
V. Westmoreland and Hundsruck. Old Red Sandstone (Devonian), Carboniferous.	E. 31° 30′ N.	Wales and adjoining English counties, Westmoreland, the Grampians, Ireland, Eifel, Nassau, the Vosges, France, Bohemia, Scandinavia.
VI. Ballons. Millstone Grit.	W. 16° 35′ N.	Many places in Great Britain and France. Extends to Old Red Sandstone of Norway, and Devonian and Carboniferous rocks of Russia.
VII. Forez	N. 11° 50′ W.	Several parts of France. Dudley? Cross Fell? Derbyshire?
VIII. North of England. Rotheliegendes, Magnesian Limestone.	N. 2° 30′ E.	Central ridge from Derbyshire northwards, Malvern Hills, etc., Department of the Loire, etc., in France, Island of Gothland, North of Russia.
IX. Netherlands and South Wales, Gres de Vosges, and Magnesian Conglomerate of Bristol.	E. 2° 0′ N.	Extends discontinuously from the Elbe to Bride's Bay, and southward into Brittany, South of Ireland, Derbyshire, Netherlands, Thuringia, South of Russia.
X. Rhine. Trias.	N. 21° 4′ E.	Vosges mountains and centre of France, Dudley, and Coal-brook Dale, Ireland, Scotland, Scandinavia.
XI. Thüringerwald. Lias and Jurassic.	W. 36° 47′ N.	Thüringerwald, France.
XII. Mont Pilatus and the Côte D'Or. Lower Cretaceous.	E. 37° 55′ N.	Eastern and Northern parts of France, Saxony, Vosges, England (Oolitic escarpment).
XIII. Mont Viso and Pindus. White Chalk and Nummulitic formation.	N. 21° 51′ W.	Mont Viso (French Alps), Centre of France, Greece.
XIV. Pyrenees. Eocene of Paris Basin, beneath Grès de Fontainebleu.	W. 23° 3′ N.	Pyrenees, Italy, Sicily, Greece, Carpathians, south-east of England, (Weald, etc.)
XV. Corsica and Sardinia. Grès de Fontainbleau.	N. 1° 11′ W.	Corsica, Sardinia, upper part of Loire and Allier, Rhone, Hungary, Syria, Red Sea.
XVI. Isle of Wight and Tatra. Calcaire d'eau douce superieur (Paris basin).	E. 4° 32′ N.	Isle of Wight, Tatra (a mountain south of the Carpathians), Greece, Eastern Alps, Jura.
XVII. Erymanthus and Sancerrois. Faluns de la Touraine, Molasse (containing shells).	E. 22° 18′ N.	Greece, France.

System.	Orientations reduced to Bingerloch.	Regions in which Systems exist.
XVIII. Western Alps. Terrain de transport ancien.	N. 28° 19 E.	Italy, Sicily, Northern Africa, Hungary, Poland, Crimea, Asia Minor, the Hartz, Cantal and Mont Dor, Norway, Sweden.
XIX. Principal Chain of the Alps (from Le Vallais to Austria). Diluvium.	E. 15° 6 N.	South-east of England, North of France, south-west of France, Spain, shores of the Mediterranean, North of Africa, Atlas, Caucasus.
XX. Tenare, Etna, Vesuvias.	N. 15° 46′ W.	Greece, Italy, Sicily.

Any well-informed geologist, who even casts his eye along this table, will feel that, however the earlier systems may be open to arguments for or against, the endeavour to support the later ones by any fair show of reasoning, or anything else but the most arbitrary assumptions, must be perfectly hopeless.

If the present mountains of the globe have in reality been formed by forces which were simultaneously in action over the whole of it, instead of now in one part of it, and now in another, we are not yet in a position to discuss the law which has regulated that action. It seems much more likely, that the forces residing in the interior of the globe have acted locally and intermittingly, the area of the localities acted on, and the times of the activity, and the pauses between them, having been very various but never excessive, the areas not exceeding those which we know to have been simultaneously affected by earthquakes during our own times, and the times of action and repose being of similar length to those with which we are now familiar.

The earthquakes which now affect the surface of our earth are but the external symptoms of the occasional convulsive movements going on at greater depths, those movements producing contortions or dislocations, or great curvatures in the rocks deep below the surface, such as when they reach the surface after long equable elevation and great denudation will shew exactly the same phenomena as we observe in the mountain chains and disturbed districts now visible at the surface.

CHAPTER XXI.

MINERAL VEINS.

THE local accumulation or deposition of minerals in parts of rocks, subsequently to the formation of the rocks themselves, is a very interesting and important subject, which requires a special treatise for its proper discussion. All that can be done here is to point attention to a few of the principal facts connected with it.

Metallic Ores in Beds.—The ores of metals are sometimes found to occur in beds. This is especially the case with the most abundant of all metals, iron. The great majority of rocks contain iron, and some are so highly impregnated with it as to make it worth while to smelt them. The so-called iron-sands of the south-east of England were at one time an important source of iron. The principal sources now used in Great Britain are beds of clay-iron-ore, or beds containing nodular concretions of clay-iron-ore, found in the Carboniferous and other formations.

Hæmatite also occurs in great bed-like masses in some places, as near Ulverstone, where a bed-like mass 20 or 30 feet thick, appears as if interstratified with the Carboniferous Limestone (*See Mems. Geol. Survey*, Iron Ores of Gt. Britain, part 1. Introduction by W. W. Smyth, p. 20.)

Some beds of rock also contain copper-ore as a mechanical deposit, mingled with the other materials of the rock. The "kupfer schiefer," or copper slate of Germany, is of this character, and many beds of sandstone in the upper part of the Old Red Sandstone of the south of Ireland, contain considerable quantities of copper-ore disseminated among them.

These, and such like accumulations of the ores of metals, do not properly belong to the subject to be treated of in this chapter, the metallic ore having in them been deposited in the same way as the other materials of the bed or beds in which it lies, either as a chemical precipitate or a mechanical sediment.

When, indeed, the metallic ore no longer remains in the exact form or place in which it was first deposited; but has segregated itself from a state of general dispersion through the mass of a rock, so as to form nodules or concretions in particular parts of it, like the balls of clay-ironstone in many clays, or the balls of fibrous radiating iron pyrites in

chalk, or the cubical and other crystals of iron pyrites in many rocks, there is then an obvious connection between such a phenemenon and those to be found in metallic veins. This concretionary action, however, is not confined to metallic ores, but is general for all mineral matter, as is shewn by the segregation of flints in chalk, chert in limestone, calcareous concretions in clays and sandstones, the formation of hard balls in shales, and that of botryoidal and other globular masses in dolomite.

We are led, moreover, by almost insensible steps, from the study of such molecular movement in the particles of rocks after deposition, through other occurrences, up to the phenomena observable in mineral veins.

It often happens that in breaking open balls of clay-iron-ore, crystals of galena (sulphide of lead) and of blende (sulphide of zinc) are found in the cavities of the ball. Nodular lumps of specular iron ore, highly crystalline and the size of the fist, are found sometimes in the Old Red Sandstone of the South of Ireland, and similar balls of galena in the Carboniferous Limestone. These are not rolled pebbles, but small deposits of the minerals which have been formed in little closed cavities in the rock.

Pipe Veins.—Much larger depositions of lead ore, and of other minerals, occur occasionally in rocks, filling up irregular cavities that have apparently little or no connection with any great fissure. What are called "pipe veins," in Derbyshire and the North of England, are of this nature. Curious bunches of lead ore in such irregular cavernous spaces, occur not unfrequently in the Carboniferous Limestone. One that I have examined with Mr. R. J. Foot, a little west of Tulla in county Clare, shewed an irregularly formed chamber in the limestone, apparently twenty yards across in some places, descending nearly vertically, and lined with an immense deposit of calc spar. Crystals of galena seem to have been deposited together with those of calcite, especially towards the central part of the hollow, and to have been more or less completely worked out many years ago.

Several other such casual deposits have been worked in that neighbourhood, and also in the counties of Kerry, Limerick, Dublin, and in many other places both in Ireland and in Great Britain.

Some of these may possibly be connected with large longitudinal and vertical fissures, and may thus be looked upon as enlargements of true mineral veins or lodes. Others, however, are certainly not so, but mere local depositions of crystalline mineral matter, spar or ore, in caverns or cavernous spaces which were formed in the limestone, like all other caverns, by the erosion of acidulous water.

True Lodes or Mineral Veins.—A true "lode" or mineral vein may be described as a large fissure, often, perhaps always, a fault, in the

open parts of which crystalline mineral matter has been deposited. It follows that it is always of long subsequent date to the rock found on each side of it.

In veins or dykes of igneous rock, we have seen that they are either *veins of segregation* with or without fissures, or *veins of injection*, liquid matter having been forced into fissures, either previously existing or formed at the time of injection. There is commonly in such veins no farther dislocation of the adjacent rocks than will allow of the intrusion of the igneous matter.

We have also seen that in "faults" the fissure will probably be closed in soft and easily compressible rocks, while in hard ones it will often stand open, either wholly or in part, the walls or sides of the fissure being kept asunder by the knobs and protuberances which result from the irregularities of its form.

It is of course quite possible that molten matter may gain access to such a fissure, and fill it up with a dyke or vein of igneous rock. If, however, it be not so filled up, it will be ultimately more or less completely filled with other kinds of mineral matter, and in a different way.

Blocks and fragments of the adjacent rocks may fall into such a fissure, and such blocks are often found in mineral veins. If it have anywhere any open communication with the surface, different matters may be swept into it by floods or springs. Branches of trees, gravel, sand, and clay, and other surface matters, have accordingly been found in mineral veins.

Besides these matters, however, thus introduced by mechanical causes, many minerals have been chemically deposited in fissures, and it is to these chemically-deposited substances that we look as the true contents of a *mineral vein.*

The number of minerals found in such veins is far greater than that of the minerals forming the principal constituents of rocks, for not only are there many earthy minerals in addition to quartz and carbonate of lime, such for instance as fluor spar, barytes, or heavy spar, strontianite or carbonate of strontia, and others which are generally called *spars*, but various *ores* of copper, lead, tin, iron, zinc, mercury, antimony, silver, etc. Some of these metals sometimes occur pure or native, and gold is always so found.

It is to these metallic minerals that the miner of course chiefly looks, and he generally speaks of the earthy minerals, as the gangue, matrix, or vein stuff of the "vein" or "lode."

The mineral contents of a vein are sometimes confusedly dispersed through it, the "vein stuff" being either crystalline or amorphous, and the ore occurring either as disseminated crystals or nests, or as "strings" or "ribs." Sometimes there appears a regular arrangement of the

various substances, the "cheeks" or "walls" of the "lode" being lined with a layer of crystals of one kind of substance, with their points or apices directed inwards, each of these layers being covered by a crystalline layer of another substance impressed by the crystals of the first, and therefore evidently deposited upon it, and after two or three such alternations a rib of ore is found in the centre (fig. 102).

In other instances the vein will be filled with only one kind of substance, sometimes the "vein stuff," sometimes the ore.

Such structures as that in fig. 102 seem necessarily to involve the idea of successive depositions of the different coatings or linings of the vein, the central rib of ore being the last or newest.

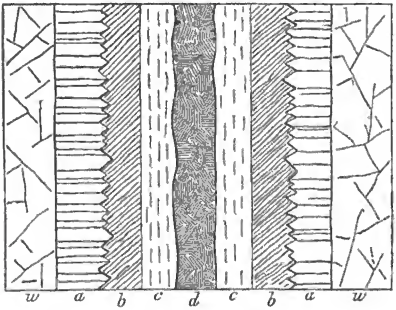


Fig. 102.

a. Coating of one mineral, say quartz.
b. Coating of a second mineral, say fluor spar.
c. Coating of first mineral, or of a third, say sulphate of baryta.
d. Rib of ore, as copper or lead.
w. w. Walls of the lode.

Assuming, however, the vein to have been filled with an aqueous solution of these minerals, it is not absolutely necessary to suppose them to have been successively introduced, since all the substances may have been in solution together, and circumstances having been favourable at one time to the deposition of one substance and to that of another at another time.

In some veins it appears that after being filled up, subsequent movements have taken place, causing fresh openings, and new deposits of crystals have been formed in these openings. (See *Geol. Rep. on Cornwall*, etc., by Sir H. T. Dela Beche, p. 344.) These subsequent movements have often produced shining striated surfaces, the effect of

enormous friction, which are known as "slickensides;" but these are not confined to veins, since they are found in "faults," and in broken or contorted and fractured rocks of all kinds, where a grinding motion has been communicated to different parts of the rock.

It commonly happens that in a district containing mineral veins two sets of fissures can be observed, those of each set being parallel to each other, and crossing the other set at right angles, or nearly so.

In this case the one set are called the "right lodes" and the other the "cross courses." The two sets of fissures may either be of contemporaneous origin or one subsequent to the other.

If a mineral vein be inclined from the perpendicular, and they are seldom absolutely vertical, and it be traversed by any subsequent fissure, producing dislocation, and therefore being a fault, it will follow that the first-formed vein will be thrown up or down by the second, just in the same way as if it were a bed. Where it appears at the surface, therefore, it will appear as if it had had a lateral shift, just in the same way as a bed will.

If at p. 249 fig. 43 *a a* be a vein instead of a bed, the explanation there given of the apparently lateral movement of *a a* will equally hold good.

In studying the intersection of fissures or veins, however, there is a source of error to be avoided which could not arise in the case of a bed cut by a fault, since it may happen that the apparent shifting at the surface may not be due to any dislocation of one vein by the other at all. They may both have been produced simultaneously, one or the other not having been continued exactly in the same straight line. It may happen, too, that, instead of *b b′* having cut through and shifted *a á* (fig. 103), *b b′* may have been the first formed, and that when *a á* was subsequently produced, it ran along *b b′* for a certain space before it was continued into the "country" on the other side of it.

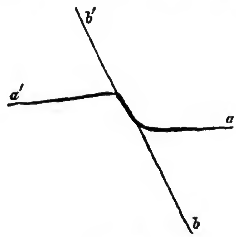


Fig. 103.

Great care, therefore, is necessary in examining the intersections of mineral veins, before deciding on the relative age or on the exact nature of the dislocations that have caused or affected them.

Where "lodes" and "cross courses" occur together in a district, their contents are often different, one kind of minerals being found in one and another in the other. Where the date of the "cross course" is newer than that of the "lode," which is often the case, it is easy to understand the difference in their contents. When, however, the

two veins are contemporaneous, as sometimes happens, it is not so easy.

Sometimes the cross courses contain no ores themselves, but the parts of the right lodes near the cross courses are found to be more than usually rich.

Both in the north and west of England the "right lodes" run nearly east and west, the "cross courses" nearly north and south.

Mode of Deposition of Minerals in Veins.—Of the various hypotheses proposed to account for the origin of the contents of mineral veins, none perhaps are altogether satisfactory. Mr. Were Fox called attention to the fact of currents of electricity traversing veins, and there appears no difficulty in supposing that if veins are filled with water more or less acidulated and impregnated with mineral solutions, a great natural "electro-plating" process may be set up, by which different minerals may be deposited at different times or in different parts of the walls of the lodes. Where the minerals, however, and especially the metallic ores, are derived from, is another question, whether directly from original repositories below, or indirectly by segregation, or by solution in minute particles from the adjacent rocks. That the fissure should remain open for a great and indefinite period of time, and that its sides should be hard rock, seem the two essential conditions, though perhaps the latter may only be necessary to ensure the former.

The mineral contents of veins seem to be by no means permanent, even when complete, since crystals of minerals are often found that have not their true form, but the form of some other mineral; the originally deposited crystal having decomposed and been removed, and the newer one deposited in its place. Vast periods of time must have elapsed for such processes to have taken place.

It must be borne in mind (as is shewn by Sir H. De la Beche in his Report on Cornwall and Devon, chapter xii., and his Geological Observer, chapter xxxv.) that at the time the minerals were deposited in veins those veins were probably beneath the sea, and also that they were covered with a great thickness of rock which has since been removed by denudation. The parts that are now worked were therefore much deeper in the earth at the time the minerals were deposited, and the rocks and the water which percolated through them had a much higher temperature than they have had since their denudation. The water may even have been in the state of vapour. It is clear that either hot water or steam, with or without the assistance of electricity, might set many chemical actions and reactions at work that would be likely to cause the deposition of crystalline minerals. The frequent occurrence of pure uncombined silica, either as crystalline or amorphous quartz, seems to require the presence of water, probably at a high temperature.

The experiment of Mr. Jeffries, mentioned at p. 50, shews that hot

water traversing the adjacent rocks might dissolve some of the silicates and deposit the silica in an uncombined state.

Another method by which the minerals might be brought from the lower and more intensely heated portions of the earth's crust is by sublimation. The metallic ores might gain access to the lower parts of deep fissures in a state of vapour, and be deposited on the walls of the fissures as the vapour rose to a cooler level. That this is quite possible is shewn by what takes place now at smelting works and refineries.

When walking across the Allenheads mining country after the meeting of the British Association at Newcastle, in the year 1838, a chimney, a mile long, built up the side of a hill near one of Mr. Beaumont's mills in the county of Northumberland, was pointed out to me. It had chambers in it at intervals, and it was said that its expense was repaid in a few years by the quantity of lead deposited in these chambers, which would otherwise have been dissipated in the state of vapour into the atmosphere. It was the noxious action of these mineral vapours on the surrounding crops which first necessitated the erection of the chimney.

As this happened so many years ago, I wrote to Mr. Sopwith, the eminent manager of Mr. Beaumont's mines, respecting it, and in answer I was informed by him that formerly "large quantities of lead were carried off in the state of vapour and deposited on the surrounding land, where vegetation was destroyed, and the health of both men and animals seriously affected. This led to various extensions of the horizontal or slightly inclined galleries in use at Mr. Beaumont's mines, and the quantity of lead extracted rapidly repaid the cost of construction. The latest addition of this kind was made at Allen Mill, and it completed a length of 8789 yards (nearly five miles) of stone gallery (or chimney) from that mill alone. This gallery is eight feet high and six feet wide, and is in two divisions widely separated; one being in use during such times as the *fume* or deposit (a black oxide of lead) is taken out of the other. There are also upwards of four miles of gallery for the same purpose connected with other mills belonging to Mr. Beaumont in the same district and in Durham, and further extensions are contemplated. The value of the lead thus saved from being totally dissipated and dispersed, and obtained from what might be called *chimney scrapings*, considerably exceeds ten thousand pounds sterling annually. It should be observed, however, that the mines of which these chimneys or flues are an appendage, are the largest lead mines in the world, and that the royalties or freehold rights of mining belonging to Mr. Beaumont, in the county of Northumberland alone, extend over more than a hundred square miles, in addition to extensive leasehold mines in the county of Durham."

The fact that the metallic ores are more frequently combinations

with sulphur, arsenic, etc., than with mere oxygen or carbonic acid, is rather in favour of their having been sublimed from the interior of the earth. In lodes containing copper it usually happens that the upper part or "back" of the lode has been more or less converted into carbonate of copper (malachite) and oxides, while the lower part contains sulphides or other combinations.

The hypothesis of sublimation, however, does not agree very well with some facts that are observable in some mineral veins. It happens occasionally, for instance, that the very substance of the rock on each side of the vein is impregnated with ore, little detached crystals of the mineral occurring in the rock, or little streaks or strings of ore spreading into it without any apparent fissure for their reception. Sometimes in the north of England the limestone near a lead vein looks as if made up of alternate horizontal laminæ of limestone and galena, each about half an inch thick, the laminæ of galena gradually thinning out as they proceed into the body of the limestone. It would have been impossible for the place of these laminæ of galena ever to have existed as small open horizontal fissures, since the laminæ of limestone between them would have been destitute of any support, and could not have remained without it.

The strings and laminæ of the ore look more as if they were the feeders of the vein than as if they had proceeded from it. One might imagine them to have been deposited in water oozing from the mass of the rock into the vein, dissolving the limestone, and leaving the lead ore in its place, more naturally than in any other way. These horizontal veins are called "flats," and they appear to be sometimes of very considerable magnitude, extending for many yards into the adjacent rock.

Occurrence of Gold.—The great auriferous veins of white quartz (not quartz rock) which traverse the rocks of many parts of Australia and other countries, must almost certainly have been formed through the influence of water. The gold is deposited in the crevices and interstices of these quartz veins, and the nuggets sometimes assume strangely fantastic shapes, like those taken by molten lead when poured into water. This has apparently led the gold diggers to suppose that the gold was in a molten state when it was deposited in the veins, a supposition so highly improbable that it does not need serious refutation. What was the exact method of its formation, or what are the circumstances which conduce to the accumulation of gold in one locality more than in another, is not known to any one. This, as a part of the whole problem of mineral veins, must await solution from the future researches of science.*

* Scientific men are sometimes accused of rashly theorising. The accusation is not altogether devoid of foundation, though it may oftener be brought with truth against men who

Gold and tin ore are often found in sufficient quantities in the "drift," or the loose clays, sands, and gravels which cover a country, to pay for extracting them by washing. These are called "stream works," or "washings," or "diggings." The superficial materials which cover the solid rocks are derived from the waste and erosion of those rocks, or of other rocks in the adjacent district. The destruction of the rocks of course involves that of the veins contained in them, and the ores being much heavier than the stony materials of the rocks are removed to less distances than the stony portions. Large portions of the eroded materials being swept completely away, those that remain are for this reason comparatively very rich in the metallic portions—richer, perhaps, than the mass of the rocks were themselves originally.

Nature has in this case partially performed the very action by which man artificially extracts ore or metal from the rocks, pounded them down and washed the materials so as to separate the heavier from the lighter.

Association of Minerals in Veins.—The association of different minerals in different veins, may some day throw more light on the nature of the processes by which they were deposited. Werner, for instance, says that galena or lead glance, copper pyrites, blende, and calamine frequently occur together; as also cobalt, copper, nickel, and native bismuth; tin, wolfram, tungsten, molybdena, and arsenical pyrites, etc. It appears that magnetic iron (the emery of the gold diggers) generally occurs with gold. Silver also is commonly found in lead ore, most usually in such quantities as to make its separation a paying process. Recent experiments of Dr. Percy shew us that minute quantities of gold occur in almost all lead ores, as well as in all copper and iron pyrites.

Relations between contents of Vein and nature of surrounding Rock.—The relation between the contents of mineral veins and the nature of the rock which they traverse is also important. The lead veins of the north of England traverse limestones, sandstones, and shales, and their contents vary according to the nature of the substances which form the walls of different parts of the "lodes." It is even said that the "lodes" vary in contents in different beds of limestone, but it does

have only a popular reputation for science, than against those whose claims to the title are recognised by their brethren. If, however, partial or imperfect knowledge sometimes indulges in vain or hasty speculation, it must yield the palm in this respect to blank ignorance. The flights of men who are unincumbered by the least particle of knowledge leave far behind the aerial excursions of those who are even slightly weighted with it. One gentleman lately published a large book on the gold mining districts of Australia, in which he attributed the occurrence of gold in the drift of that country to the disappearance of a *soluble lava!* which had been ejected over the whole country to a depth of many hundred feet, and had been subsequently melted away, and left the particles of gold it contained behind it.

not appear that the richness of a lode is constant for any beds of limestone. When one or both walls consist of shale, the lode is always poorest, but this may be the result simply of the greater contraction of the fissure and the more unstable condition of its walls when soft than when they are hard.

In Derbyshire the lead veins (*rake* veins as the true lodes are there called, in contradistinction to the *pipe* veins) traverse both the Carboniferous limestone and the contemporaneous beds of igneous rock called toadstone. The very same rake veins have been found very productive in ore in the limestone, both above and below the toadstone, while where they traverse that rock they never contain ore and rarely even spar. They are indeed scarcely at all traceable in the toadstone, the walls of the vein being close together and only marked occasionally by a little string or leader of spar of some kind.

The greenstone and ash being tougher rocks than the limestone, it is probable that the original fissure was less open in them than it was in the limestone, while it is certain that water subsequently traversing that fissure would readily dissolve its limestone walls, and thus enlarge the fissure between them, while it would have no such effect on the toadstone. These facts are greatly against the idea of the lead having come from below into the part of the vein above the toadstone, since that bed is very widely spread beneath the richest of the old mining districts there. The upper part, at least, then, of these veins must either have derived their contents from above, or must have extracted them from the adjacent rocks. But there is no perceptible distinction as to the abundance of ore, or its mode of occurrence in the beds above and the beds below the toadstone.

Fallacious appearance of connection between Age of Rock, or Igneous Origin of Rock, and Occurrence of Veins.—The apparent relation between the mineral veins of the British islands and the age of the rocks they traverse is probably an accidental one only. Mineral veins may be expected in all highly-indurated and greatly fractured rocks, whatever may be their geological date.

Neither does the connection between mineral veins and the occurrence of igneous rocks appear to be better founded, than on the probability that igneous rocks will be most likely to be found in the same indurated and fractured districts which we have seen to be essential for the production of mineral veins. In most of the mining districts in which igneous rocks occur, large parts of the igneous rocks may be shewn to be of contemporaneous date with the stratified rocks in which they lie, and even the intrusive masses and igneous veins and dykes were almost always in existence before the commencement of the fissures, which have, some time after their own formation, become the repositories of minerals, and are therefore termed mineral veins.

Mining districts, then, like Cornwall, in which the "lodes" occur among many masses of igneous rock, some of which, more or less, resemble the lodes in their mode of occurrence, are not the best in which to study the subject of the origin of mineral veins, since the student is apt to be misled into the opinion, that the granites and elvans and porphyries have an essential rather than an accidental connection with the lodes. The north of England, where the rocks are of a much simpler character, forms a better type of a mineral vein district, after observing which the student may examine the Cornwall district, or others resembling it, with less chance of his being led away by the prepossessions of the miners.

NOTE. At the Ballycorus lead smelting works, near Dublin, a long chimney has lately been carried up the side of the hill for a distance of about a mile, the cost of the construction being repaid by the lead regained from it, as in the case of Mr. Beaumont's mines.

CHAPTER XXII.

THE ART OF MINING.

A FEW words on this subject may perhaps be useful.

Bed Mining.—In mining for coal, ironstone, salt, or other stratified substances, the miner has to deal with matters which occur in regular order, occupy a fixed and definite place in a series, and which, in the majority of instances, lie in the ground either horizontally or at but a slight angle of "dip." His object is to extract as much of the bed as possible, and the difficulties he has to contend with are—

1st, The support of the "roof" of the part immediately adjacent to the place where he is working, and over the galleries and passages which lead from the "shaft" to different parts of the mine.

2d, The influx of water.

3d, The ventilation of the mine, so that the miners may have sufficient air to breathe.

4th, In the case of coal mines, the foul gases which emanate from the coal, viz., the inflammable carburetted hydrogen which he calls "fire damp" or "sulphur," and the suffocating carbonic acid which he calls "choke damp."

The roof is supported either by leaving pillars of the bed which is being extracted, or by wooden props, and these are either afterwards removed, partially or completely, or left, according as the roof may be "sound" or "tender."

Coal mining is generally conducted in one of two ways, "the long wall" method, or the "post and stall" method. In the former, the miner, after reaching the extent of the mass he is going to get, works back along the whole width of his coal, supporting the roof behind him and over him by wooden props, of which he removes the farther row as he proceeds, and allows the roof to fall in over the part he has left. Where the roof is tough, this method may be adopted without danger, and in some cases the roof will gradually bend down, and the floor gradually swell up so as to meet it, and thus the rocks above and below the coal close together, as if the coal had never been there.

The "post and stall," or "bord and pillar" method, is more complicated. The whole bed of coal being intersected by two systems of galleries at right angles to each other, and being thus divided into

blocks, each block is "got" separately, either piece-meal or at once, so that pillars and ribs of coal are left in each space till the very last. These are then finally removed if it can be done without danger, and the deserted or "gotten" part of the mine is sometimes shut off from the rest either by walls of rubbish or of brick regularly built.

Care has always to be taken to keep up ventilation by carrying a current of air through every part of the mine. For this purpose, there are either two shafts, or one shaft divided into two or three compartments, one of which is the "down-cast," or that by which fresh air goes down into the mine, and the other the "up-cast," or that by which the air comes up out of the mine. The air coming down is carefully conducted along one set of galleries or gate-roads, and prevented from having any cross communication with the other set, so that it is compelled to travel into every hole and corner of the mine in order to arrive at the "up-cast" shaft, where fires are kept to cause it to ascend, or other contrivances adopted for "sucking" it out of the mine.

This current is ordinarily kept sufficiently strong to carry off any foul gases, though a sudden escape of fire-damp from some natural reservoirs, or from some old workings, sometimes produces fatal results. Too strong a general current is not always advisable, for in some cases the old rubbish contains a sufficiency both of iron pyrites and coal for the generation of great heat by decomposition, which too strong a perpetual current might fan into combustion and "fire the mine."

Vein Mining.—In vein mining the miner has to deal with substances occurring very irregularly, and according to no fixed rule whatever. The fissures themselves, which subsequently became the receptacles of the minerals, are mere accidents; they are cracks in the rocks which, even in those cases where their direction is more or less fixed, may just as well have occurred in one place as another. No amount of investigation by either miner, or geologist, or any one else, will enable any one to tell the exact spot in which a mineral vein will occur. Nothing but actually seeing the lode itself will lead any man to a knowledge of its existence.*

When the existence of a fissure or vein is ascertained, its width again is accidental; it may be several yards wide in one place, and be shortly "nipped" to a few inches, or to nothing at all, that is to say, the walls of the fissure may suddenly close together.

The third accident is the nature of its contents. A vein may be wide and regular, but its contents may either be worthless spar, or valuable ore, or any mixture of the two. A mass of pure spar may suddenly begin to contain ore, and in the course of a fathom or two

* The student may safely set any man down as a pretender (or at least as a self-deceiver) who ventures to predict the occurrence of a mineral vein by what are called "indications," unless those indications include the actual sight of a lode or a gossany vein on the back of a lode.

the vein may become very rich. A very rich vein may in the course of a fathom or two, either laterally or in depth, lose all its richness, and contain nothing but spar.

For these reasons vein mining is much more uncertain and speculative than bed mining, and no one should ever attempt it, or even take shares in a vein mining company without being prepared for these risks.

Veins are usually much more highly inclined than beds, approximating generally to the perpendicular as much as beds do to the horizontal.* They are worked by means of shafts, and horizontal galleries, one principal drawing shaft generally communicating with the whole; the climbing shafts by which the miners reach the different parts of the mine being much shorter, and very numerous, communicating with the different levels.

The difficulties the vein miner has to contend with are, in some cases keeping the walls apart when the ore is extracted, and in all cases preventing the old rubbish of the upper workings from rushing down into the deeper parts of the mine where the present workings are going on.

He is not troubled, like the coal-miner, with want of ventilation or the escape of foul gases from the rocks around him.

Having sunk a shaft so as to cut the vein, if that be at all inclined, or sinking down along the vein in many instances, he drives horizontal galleries along the vein at different levels, generally at intervals of ten fathoms, so as to have ten fathom, twenty fathom, etc., levels, and then proceeds to cut away the contents of the vein below or above each of these levels, carrying it as it is gotten along the level to the drawing shaft. Then building stages or platforms of wood to contain the rubbish, at intervals, between the levels, and to prevent that or other matter falling from one level to another, he sinks the original shaft lower and lower, continuing his galleries and cross cuts, with minor shafts communicating with them, and thus continues his explorations sometimes to depths of as much as half a mile.

This must, of course, be taken as a mere generalized sketch of the mode of operation. Works in large mines are going on simultaneously on many different levels, and in different parts of the mine.

The vein miner has one difficulty in common with the bed miner, namely, the influx of water.

In coal mines there is usually one shaft, or one compartment of a shaft, devoted to the pumping engine. This is placed, of course, on the "deep" part of the colliery, or that towards which the rest of the bed to be gotten dips. The water is then pumped up by means of a steam engine, out of a "sumpf," or hole, sunk rather below the bed.

* The student will of course understand that beds may occur at any angle whatever, and that some beds of coal even are worked at high angles, as in the south of Ireland and the Belgian coal-fields.

In vein mines it is more often possible and profitable to drive an "adit level," or gallery, from some neighbouring valley or low ground, so as to cut the vein below the higher ground which it traverses, and so drain all the part above the "adit level." When the deeper parts of the mine are afterwards "unwatered," the water is pumped up to the adit level instead of up to the surface.

Explanation of some Mining Terms.—The following is a brief explanation of some mining terms which the student may meet with in the course of his researches :—

Adit—The gallery or level driven in from some neighbouring low ground to cut a vein.

After-damp or Choke-damp—Carbonic acid gas, which usually succeeds to an explosion of "fire-damp" in a coal mine.

Attle—The refuse of the workings of a vein mine.

Back of a lode—The part near the surface, or that above the adit level, generally more or less affected by weather.

Board, or Brow—The gallery in a coal mine which is cut across the "face" of the coal.

Brattice—A wall of timber or brick, either dividing a shaft into compartments, or erected across a gallery either temporarily or permanently.

Buddle—a trough for washing pounded ore, and separating it from the gangue.

Costeaning—Sinking shallow pits at intervals down to the solid rock, and then driving headings at right angles to the general course of the veins in a country, for the purpose of discovering ore.

Counter, Contra, or Caunter Lode—A lode cutting a "right lode" obliquely between it and the cross course.

Country or Ground—The mass of rock through which a vein runs.

Cross Course—A lode more or less nearly at right angles to the main, or right running lodes of a district.

Deads—The rubbish left behind in working a vein mine.

Fire-damp—Carburetted hydrogen gas, which, when mixed with a certain proportion of air, becomes explosive on the application of flame. In some coal-fields it is called *sulphur*. A mixture of seven volumes of air to one of fire-damp is the most explosive compound ; when the proportions vary considerably either above or below that of 7 : 1 the mixture is not explosive.

Flucan—A vein or seam of clay, or any impure argillaceous substance occurring in a vein.

Foot Wall—The under wall of an inclined vein.

Gangue—The matrix of the ore in a vein.

Gate-road—A gallery driven along the "face" of the coal, a main

passage or road in a mine. Gate literally means that through or along which you *go*. In many towns the old streets are called gates, not because they lead to what we should now call the gates of a town, but because they were the places for *go*ing along. A gate is properly a passage, not that which stops it.

Goaf, or Gob—The more or less empty space left by the extraction of a seam of coal.

Gobbin—The refuse fragments left in working a coal mine, often piled up to support the roof in the part worked out.

Gossan—A brown ochrey substance, often found at the surface part of a lode ; it consists of oxide of iron, often in a powdery state, like ordinary iron rust, coating quartz, or other substances in the vein.

Hade—The dip of a vein or fault.

Hanging Wall—The upper wall of an inclined vein, or that which hangs over the miner's head.

Heading—A small gallery driven in advance of a gate road, or for any temporary purpose.

Holing—Cutting under a bed of coal for a certain distance, so as to deprive it of support, and allow of its falling down when cut away at the sides, or when wedges are driven in at the roof.

Horse—Commonly applied by vein miners to any large detached mass of rock occurring in a vein, or lying between two branches of a vein : by colliers to any mass of rock occurring in the coal.

Jackey or Jackhead Pit—A small shaft sunk in a coal mine for any temporary purpose.

Killas—The Cornish term for clay slate, especially when fragile and easily breaking into small fragments.

Leader—A string or small vein which leads to the main vein, or is supposed to do so.

Peach—Any soft green chloritic-looking substance in a vein.

Pitch—A portion of a vein prepared and set apart for working.

Pit eye—Coal left surrounding the bottom of a shaft, so as to prevent the rocks about it or the shaft itself being shaken.

Prian—A Cornish term for soft white clay in a vein, which is supposed to be a good indication of ore.

Shoad-stones—Fragments of ore found in a stream below where it crosses a vein ; *shoading* is searching for these stones in order to find the vein. Sometimes the stream may be banked up so as to make a small lake or pond, which is then suddenly let loose in order to wash the bed of the stream bare, and disclose any veins or lodes that may cross it.

Stemples—In Derbyshire, the shafts of the vein mines are often ascended and descended, not by ladders, but by pieces of wood, called *stemples*, fixed in the side of the shaft.

Stope, or Step—The parts of a vein in work ; one set of men having proceeded, another set follow them and excavate the next step above or below the first, according as the *stopes* are *overhand* or *underhand*. *Overhand* stopes are those where the miners excavate the stuff above a level by successive steps upwards, building stages as they proceed in order to catch the stuff as it falls. *Underhand* stopes are those in which they dig down below a level in successive steps, likewise erecting stages as they proceed, and leaving or making a permanent roof or covering to the level below.

Stowces—In the part of Derbyshire known as the King's Field, any man who can discover a vein has by ancient law the right to work it. He makes his claim by fixing up a windlass, or a small wooden model or imitation of a windlass, called a *Stowce*, which, if not removed by the lord of the soil within a certain short time, makes him owner of the mine.

Tamping—A term used in blasting either in a mine or a quarry, to signify the clay, sand, or rubbish rammed down on the powder in a bore hole, for the purpose of preventing the powder from being merely blown out of the hole as from a gun, and compelling it to *burst* the rock in which it has been drilled.

Tributers—A Cornish term for men who undertake to get a certain "pitch" of a vein for a per centage of the profits, varying perhaps from a quarter to three quarters, according to the richness or poorness of the vein.

Tubbing—In sinking a shaft for a coal-mine, if a soft incoherent bed be met with, or if a great influx of water occur in any beds, iron cylinders are built into the shaft, to prevent either the incoherent matter or the water from falling into the mine below.

Tutmen—A Cornish term for miners who excavate any matter, either rock or vein stuff, at so much a fathom or so much a ton—those who work by piece-work.

Underlie—The inclination or dip of a vein or fault.

Vug—An occasional cavity or hole in a vein.

Wheal—In Cornwall, mines are often called Wheals, a way of spelling the old Cornish name Huel, a mine.

Winze—In a vein mine what a jackey pit is in a coal-mine: a shaft not sunk from the surface, but in the mine, to communicate between the different levels. In a large vein mine, however, they are numerous and necessary parts of the workings.

PART II.

PALÆONTOLOGY.

CHAPTER XXIII.

ZOOLOGY AND BOTANY.

Definition.—Palæontology is the study of "fossils." The old geologists used to include minerals or any other distinct bodies that were found in rocks under the term of fossils. By "a fossil," however, is now meant the body, or any portion of the body, of an animal or plant buried in the earth by natural causes, or any recognisable impression or trace of such a body or part of a body.* "Fossils," then, are "organic remains," including under the word "remains," even footprints, or other such seemingly transient impressions, which circumstances have rendered permanent. MM. D'Orbigny and Pictet introduce into their definitions of the word "fossil," the time when and the circumstances under which this burial took place. It appears to me that this is not necessary. Nobody would say that shells lately thrown up on the beach, and covered with sand, were *buried in the earth,* while every accumulation of shells, or bones, or plants which could be said to be *buried in the earth* by any other than human agency, even if that burial took place last year, would be well worthy of the attention of the Palæontologist, and might be, without impropriety, spoken of as *fossil.* Here, as elsewhere, no hard line can be drawn between the present and the past. All such terms, then, as *sub-fossil* which we sometimes meet with, are inconvenient and unnecessary.

Neither can we include in a definition of a "fossil," any reference to its present state. Some fossil shells found in comparatively old rocks, such as the soft compact clays of the oolitic series, are in fact less altered from their living state than many shells included in recent coral reefs. Wood again may be found in such rocks still soft and but little

* See Lyell's Elements, fifth edition, p. 4.

altered, while in much more recent formations, it is often entirely mineralized and converted either into flint or into coal.

Petrifaction.—Any substances firmly buried in pure clay, not impregnated by any active mineralizing agent, and kept from the presence of air or water, may remain unaltered for an almost indefinite period.

In the majority of instances, however, the enclosing rock has either itself contained some active substance, or has given passage to fluids that have contained one ; or again, the constituents of the enclosed body itself have acted on each other, or on the surrounding rock, and thus the fossil has become more or less mineralized or *petrified*, as it is called. We have seen previously (p. 159, *et seq.*) that rocks themselves undergo great alteration in their internal structure in the course of time, and that minerals are changed or metamorphosed *in situ* from one into another by the gradual action of chemical laws. Fragments of animals and plants, dead, and therefore subject to the inorganic and not to the organic laws of existence, to the *mineral* laws, as they might be called, and not to the laws of life, must of course be subject to the same actions as the mineral constituents of rocks.

The hard parts of animals, especially such as bones, shells, crusts, and corals, are composed principally of those mineral substances (salts of lime, etc.) which are most easily acted on by the most frequently occurring chemical processes. In breaking open fragments of coral lying on a coral reef, the internal parts are very frequently found to be filled with a mass of crystalline carbonate of lime, obliterating or obscuring the organic structure. When shells or corals are embedded in rock percolated by water, it is almost impossible for them to escape that partial re-arrangement of their particles which shall give them an internal crystalline structure.

It has been previously stated, p. 160, that petrifaction may take place in two ways, which we may call *petrifaction by alteration*, and *petrifaction by replacement.*

If the constituent particles of a body assume a crystalline instead of an organic arrangement, whether that change be or be not accompanied by a change in the proportions of those constituents, or even by the entire abstraction of one or two of those which are only in small proportion, we may call it *petrifaction by alteration.*

If, on the other hand, the change be a total one, or nearly so, so that the whole, or nearly the whole, of the constituents of the body are removed and replaced by other substances of a different nature, then it may be called *petrifaction by replacement.*

A calcareous shell may be changed into crystalline limestone by the first kind of petrifaction, or converted into a flint or iron pyrites shell by the second. Wood may be changed into coal by the first, or into opal by the second.

Still, as this conversion is a molecular one, taking place only in the ultimate particles of the substances, which are of inconceivable minuteness, the organic structure is often perfectly preserved during even replacement petrifaction, the little internal pores or cells retaining their form so completely as to be recognised by the microscope, even in the minutest fragment of the fossil. It is as if a house were gradually rebuilt, brick by brick, or stone by stone, a brick or a stone of a different kind having been substituted for each of the former ones, the shape and size of the house, the form and arrangement of its rooms, passages, and closets, and even the number and shape of the bricks and stones remaining unaltered. The hollow spaces, however, in the interior of a fossil, are usually filled up either by the substance of the rock in which it lies, which has gained access to the interior through natural openings, or accidental fractures, or else by crystalline minerals, such as carbonate of lime, which have percolated through the pores of the walls surrounding the hollow spaces, just as they do into any other cavities in rocks.

It sometimes also happens that the substance of the fossil has been altogether removed, and merely its "mould" or impression left in the rock that enclosed it. This mould or external cast, in some instances when the original body was a hollow one, also encloses an internal cast consisting of the matter which gained access to the interior of the fossil.

Sometimes the fossil is very distinct, and can be completely detached from the matrix or rock in which it is enclosed. Sometimes, on the other hand, it is so intimately united with the matrix, and so blended with the substance of the rock, that we can only observe a section of it when the rock is broken open. Sometimes the fractured surface of the rock must be polished before we can distinguish the structure or even the outline of the fossil.

Classification of the Animal and Vegetable Kingdoms.—It is obvious that we must have some knowledge of existing animals and plants, in order rightly to understand the facts of palæontology. Fossil animals and plants are either of the same species as those now living, or of different species. In order to ascertain which of these is true, we must necessarily know the living species when we see them. Whether the species of fossils be living or extinct, in order to draw any conclusions respecting them, as to the place where they lived, for instance, and the circumstances under which they were buried, we ought to know the habits of the living species with which they are identical, or to which they are most nearly allied.

No man can become a palæontologist who is not also a biologist (botanist and zoologist); and no man can become a thorough zoologist who has not had that early training in anatomy which falls to the lot of the medical student only. To become a thorough palæontologist, then, a man must have what is called a medical education. Many

men, however, even without this, make themselves masters of a particular branch of the subject, but always with difficulty and always with a certain deficiency of authority. Good palæontologists are rarer even than good mineralogists. Still a certain amount of palæontological knowledge is more necessary to the geologist than even a smattering of mineralogy. But in order to acquire it, we must be at least acquainted with the general outlines of botany and zoology. I am accordingly induced to insert here, for the convenience of the student, such an abstract of the classification of the animal and vegetable kingdoms as shall serve to give him an idea of the totality of the organic kingdoms, both living and fossil.

The animal kingdom was divided by Cuvier into four sub-kingdoms: Vertebrata, Mollusca, Articulata, Radiata. Recent authorities have, however, divided it into five, splitting the Radiata into two, and re-arranging some of its constituents.

The following classification is one supplied to me by my friend and colleague Professor Huxley.* In perusing it the student must guard himself against taking its arrangement as strictly a linear one. The highest animals are doubtless placed first and the lowest last, and this idea of subordination runs throughout; but it is impossible to carry it out accurately in detail, since many of the orders should be arranged side by side, or still more properly, in circles, in order strictly to express their mutual relations. Those orders and genera which are entirely extinct are printed in italics.

KINGDOM ANIMALIA.

SUB-KINGDOM VERTEBRATA.

PROVINCE I.—ABRANCHIATA.

CLASS I.—MAMMALIA

Sub-class.—PLACENTALIA.

Alliance 1.

Order I. PRIMATES.

Family	1. Anthropini .	Man.
	2. Catarhini . .	Old world apes.
	3. Platyrhini . .	New world apes except Marmosets.
	4. Arctopithecini	Marmosets.
	5. Prosimii . .	Lemurs.
	6. Galeopithecini	The flying lemur.
	7. Cheiromyini .	The Aye-Aye.

* In the first edition of this work a great mistake was committed, and a great injustice done to Mr. Huxley. The paper he lent me was originally intended for his own use only,

Order II.	CHEIROPTERA.	
	Sub-order 1. Insectivora	Bat, vampyre.
	2. Frugivora	Flying fox.
Order III.	INSECTIVORA	Hedgehog, shrew, mole.
Order IV.	RODENTIA	Rat, hare, squirrel, etc.
Alliance 2.		
Order V.	EDENTATA	Sloth, armadillo, ant-eater.
Alliance 3.		
Order VI.	SIRENIA	Manatee, dugong.
" VII.	*Toxodontia* (?).	*Toxodon.*
" VIII.	PROBOSCIDEA	Elephant, mastodon.
" IX.	PERISSODACTYLA	Horse, rhinoceros, tapir, hyrax.
" X.	ARTIODACTYLA	Pig, hippopotamus, camel, ox.
" XI.	CETACEA.	Whale, porpoise.
Alliance 4.		
Order XII.	CARNIVORA	Lion, dog, bear, seal.

Sub-class.—IMPLACENTALIA.

Alliance 5.		
Order XIII.	MARSUPIALIA	Kangaroo, opossum. Dasyurus, etc.
Alliance 6.		
Order XIV.	MONOTREMATA	Echidna, ornithorhynchus.

NOTE. No linear arrangement can be expected to be natural, but it is believed that the close affinity of the orders grouped under each alliance, and their comparative distinctness from those placed in other alliances cannot be disputed.

CLASS II.—AVES.

Order I.	Raptores	Eagle, hawk, vulture, owl.
" II.	Scansores	Woodpecker, cuckoo, parrot.
" III.	Passeres	Sparrow, lark, crow.
" IV.	Columbæ	Pigeon.
" V.	Gallinæ	Pheasant, fowl, turkey, grouse.
" VI.	Cursores	Ostrich, emu, cassowary, apteryx.
" VII.	Grallæ	Crane, heron, plover.
" VIII.	Palmipedes	Duck, albatross, gull, penguin.

and for a particular purpose, and when he lent it me, I promised to let him see the proof-sheets for correction. Unfortunately, these came to me when he was in Switzerland, after great previous delay, and with an urgent request that the delay might not be repeated, and they were therefore printed off without his revision. For this edition Professor Huxley has been kind enough to supply me with a new classification, which embodies what he believes to be the most trustworthy conclusions of investigators into this subject.

Class III.—REPTILIA.

Order I.	Crocodilia	. .	Crocodile, alligator, gavial.
„ II.	Lacertilia	. .	Monitor, chamæleon, blindworm.
„ III.	Ophidia	. .	Python, rattlesnake, viper.
„ IV.	Chelonia	. .	Turtle, tortoise.
„ V.	*Dinosauria*	. .	*Iguanodon, megalosaurus.*
„ VI.	*Pterosauria*	. .	*Pterodactylus, rhamphorhynchus.*
„ VII.	*Sauropterygia*	. .	*Plesiosaurus.*
„ VIII.	*Ichthyopterygia*	.	*Ichthyosaurus.*

PROVINCE II.—BRANCHIATA.

Class IV.—AMPHIBIA.

Order 1.	Batrachia	. . .	Frog, toad.
„ 2.	Saurobatrachia	. .	Salamander, menopoma, proteus.
„ 3.	Ophiomorpha	. .	Cæcilia.
„ 4.	*Labyrinthodonta*	. .	*Mastodonsaurus, archegosaurus.*

Class V.—PISCES, nearly after Müller.

Order 1.	Dipnoi	. . .	Lepidosiren.
„ 2.	Elasmobranchii	. .	Sharks and rays, or what are commonly called cartilaginous fish, minus the Ganoids, Marsipobranchs, and Pharyngobranchs.
„ 3.	Ganoidei	. . .	Sturgeon, lepidosteus, amia, polypterus.
„ 4.	Teleostei	. .	Perch, cod, salmon, and ordinary osseous fish.
„ 5.	Marsipobranchii	. .	Lamprey and Hag.
„ 6.	Pharyngobranchii *	.	Amphioxus.

SUB-KINGDOM ANNULOSA.

PROVINCE I.—ARTICULATA or ARTHROPODA.

Class I.—INSECTA.

Order 1.	Hymenoptera	. .	Saw-fly, ichneumon, bee.
„ 2.	Coleoptera .	. .	Beetles.

* Agassiz arranges the fish into four orders, according to the structure of the scales; 1. Placoids, which includes the Elasmobranchii, and some others; 2. Ganoids, which correspond to No. 3, and some others; 3. Ctenoids, and 4. Cycloids, which together nearly correspond with the fourth order, the Teleostei.

Order 3.	Neuroptera	Dragon-fly, white ant.
„ 4.	Strepsiptera	Stylops.
„ 5.	Lepidoptera	Butterfly, moth.
„ 6.	Diptera	House-fly.
„ 7.	Orthoptera	Cricket, locust, earwig.
„ 8.	Hemiptera	Bug, cicada, aphis.
„ 9.	Aptera	Flea.

Class II.—MYRIAPODA

Order 1.	Chilopoda	Centipede.
„ 2.	Chilognatha	Millipede.

Class III.—ARACHNIDA.

Order 1.	Pulmonata	Scorpion.
„ 2.	Amphipneusta	Spiders.
„ 3.	Trachearia	Acarus.
„ 4.	Pycnogonida ?	Pycnogonum.

Class IV.—CRUSTACEA.

Order 1.	Podophthalmia	Lobster, crab.
„ 2.	Stomapoda	Squilla.
„ 3.	Edriophthalmia	Isopods, amphipods, læmodipods.
„ 4.	Branchiopoda	Daphnia, apus.
„ 5.	Copepoda	Cyclops, suctorial crustacea.
„ 6.	Ostracoda	Cythere, cypris.
„ 7.	Cirripedia	Barnacles.
„ 8.	Xiphosura	King-crab.
„ 9.	*Trilobita*	*Trilobites.*
„ 10.	*Eurypterida*	*Eurypterus, pterygotus.*

PROVINCE II.—ANNULATA.

Class V.—ANNELIDA.

Order 1.	Polychæta	Nereis, serpula, lob-worm.
„ 2.	Gephyrea	Echiurus, Sipunculus.
„ 3.	Oligochæta	Earth-worm.
„ 4.	Discophora	Leech.
„ 5.	Tardigrada ?	Arctiscon.
„ 6.	Sagittida ?	Sagitta.

PROVINCE III.—ANNULOIDA.

Class VI.—SCOLECIDA.

Order 1.	Trematoda . . .	Fluke.
„ 2.	Tæniada . . .	Tape-worm.
„ 3.	Acanthocephala . .	Echinorhynchus.
„ 4.	Nematoidea . .	Thread-worm.
„ 5.	Gordiacea . . .	Hair-worm.
„ 6.	Turbellaria . .	Planaria.
„ 7.	Rotifera . . .	Rotifer, brachionus, lacinularia.

Class VII.—ECHINODERMATA.

Order 1.	Holothuridea . .	Sea-cucumbers, trepang.
„ 2.	Echinidea . . .	Sea-urchins.
„ 3.	Ophiuridea . . .	Sand-stars.
„ 4.	Asteridea . . .	Star-fish.
„ 5.	Crinoidea . . .	Feather-star, stone-lily.
„ 6.	*Blastoidea* . . .	*Pentremites.*
„ 7.	*Cystidea* . . .	*Cryptocrinus, Apiocystites.*
„ 8.	*Edrioasterida* . .	*Agelacrinites.*

SUB-KINGDOM MOLLUSCA.

PROVINCE I.—ODONTOPHORA.

Class I.—CEPHALOPODA.

Order. 1.	Dibranchiata . .	Squid, argonaut, poulpe, cuttle fishes, *belemnite.*
„ 2.	Tetrabranchiata . .	Nautilus, *ammonite.*

Class II.—PTEROPODA.

Order 1.	Thecosomata . .	Hyalæa, creseis (dentalium ?)
„ 2.	Gymnosomata . .	Clio, pneumodermon.

Class III.—PULMONATA.

Order 1.	Inoperculata . .	Helix, limax.
„ 2.	Operculata . . .	Cyclostoma.

Class IV.—GASTEROPODA DIŒCIA.

Order 1.	Pectinibranchiata .	Whelk, periwinkle.
„ 2.	Scutibranchiata . .	Haliotis (ear-shell).
„ 3.	Tubulibranchiata .	Vermetus.
„ 4.	* Cyclobranchiata .	Limpet, chiton.

* These four orders are Cuvier's. They are artificial, and must be looked upon as provisional, until the Gasteropoda are more thoroughly examined. (T.H.H.)

CLASS V.—GASTEROPODA MONŒCIA.

Order 1.	Nudibranchiata . .	Doris.
„ 2.	Tectibranchiata . .	Aplysia.
„ 3.	Inferobranchiata . .	Diphylliia.

PROVINCE II.—LAMELLIBRANCHIATA.

CLASS VI.—CONCHIFERA.

Orders.	No good orders have yet been established, neither Dimyaria and Monomyaria, nor Pleuroconchs and Orthoconchs, being good natural divisions.	Oyster, mussel, cockle, venus, and all ordinary bivalves.

PROVINCE III.—MOLLUSCOIDA.

CLASS VII.—BRACHIOPODA.

Order 1.	Brachiopoda articulata .	Terebratula, *leptæna*, *spirifera producta*.
„ 2.	Brach. inarticulata . .	Lingula, orbicula, crania.

CLASS VIII.—POLYZOA.

Order 1.	Cheilostomata . . .	Flustra, eschara.
„ 2.	Ctenostomata . . .	Bowerbankia.
„ 3.	Cyclostomata . . .	Tubulipora.
„ 4.	Lophophea . . .	Plumatella.
„ 5.	Pedicellinida . . .	Pedicellina.

CLASS IX.—ASCIDIOIDA.

Order 1.	Branchialia . . .	Cynthia, ascidia.
„ 2.	Abdominalia . . .	Clavellina, aplidium.
„ 3.	Larvalia	Appendicularia.

SUB-KINGDOM CŒLENTERATA.

CLASS I.—ACTINOZOA.

Order 1.	Ctenophora . . .	Cydippe, cestum.
„ 2.	Alcyonaria . . .	Alycyonium, gorgonia, pennatula, tubipora.
„ 3.	*Rugosa*	*Cyathophyllum*, *cystiphyllum*.
„ 4.	Zoantharia . . .	Actinia, zoanthus, antipathes, madrepora, astræa.

Class II.—HYDROZOA.

Order	1. Hydridæ	Hydra.
„	2. Corynidæ	Coryne, tubularia, eudendrium.
„	3. Sertularidæ	Plumularia, sertularia.
„	4. Calycophoridæ	Diphyes, sphœronectes.
„	5. Physophoridæ	Physalia, velella, physophora.
„	6. Lucernaridæ	Rhizostoma, cyanœa, lucernaria.
„	7. Medusidæ	Ægina.

SUB-KINGDOM PROTOZOA.

PROVINCE I.—STOMATODA.

Class I.—INFUSORIA.

Paramœcium, vorticella, acineta, noctiluca.

PROVINCE II.—ASTOMATA.

Class I.—SPONGIDA.

Spongilla, halichondria, tethya.

Class II.—RHIZOPODA.

Order	1. Lobosa	Amœba.
„	2. Radiolaria	Thalassicolla,* dictyocha, acanthometra, actinophrys.
„	3. Reticularia	Gromia, rotalia, *nummulites*, miliola.

Class III.—GREGARINIDA.

Gregarina.

[*Incertæ sedis*, Mycetozoa (?) . . Œthalium.]

It is less necessary for the geologist to understand the details of the classification of the Vegetable Kingdom, and I shall therefore give only its great sub-divisions, taken from the programme of the lectures in the Museum of Irish Industry.

* "Marine jelly," from the Greek words "Thalassa," the sea; and "Kolla," jelly.

VEGETABLE KINGDOM.

Class I.—THALOGENS.

		Examples.
Order	1. Algæ	Sea-weeds.
„	2. Fungi	Mushrooms, etc.
„	3. Lichens	Tree and stone mosses, etc.
„	4. Characeæ	Chara, etc.

Class II.—ANOGENS.

Order	1. Hepaticæ	Liverworts.
„	2. Musci	Mosses.

Class III.—ACROGENS.

Order	1. Lycopodiaceæ	Club-moss, etc.
„	2. Marsiliaceæ	Pepper-worts, etc.
„	3. Equisetaceæ	Horse-tails.
„	4. Filices	Ferns.

Class IV.—ENDOGENS.

Order	1. Glumiferæ	Grass, etc.
„	2. Petaloideæ	Banana, orchis, palms, lilies, screw-pines, etc.
„	3. Dictyogenæ	Yam, smilax.

Class V.—EXOGENS.

Order	1. Apetalæ.	
	a. Gymnosperms	Pine, cypress, cycas, etc.
	b. Angiosperms	Spurge, nettle, oak, elm, etc.
„	2. Corolliflorae	Primrose, convolvulus, heath, etc.
„	3. Calyciflorae	Dandelion, campanulæ, rose, pea, etc.
„	4. Thalamifloræ	Crows-foot, poppy, geranium, etc.

Of the above classes, I., II., III., form the Cryptogamia, and IV. and V. the Phanerogamia of Linnæus—the Acotyledons and Cotyledons of some authors—while I. and II. constitute the Cellulares, and III., IV., and V., the Vasculares of other authors.

Distribution of Animals and Plants. — Every one is acquainted with the obvious fact, that the individuals of the different species of animals and plants are not indiscriminately scattered about the earth, but that those of each kind are naturally limited to a particular region, of which the species is commonly said to be *the native.* Palm trees, bananas, and pine apples, do not grow in the open air in temperate zones; nor apples, barley, or potatoes, on the low lands of the tropics. The polar bear, and the lion, the reindeer, and the camel, the musk ox, and the giraffe, do not inhabit the same regions.

If we ask why these different species cannot live beyond certain limits, the answer would be, *that a climate, different from that in which they now live, would not be suitable to them.* We arrive then, first of all, at the conclusion that the limitation of species depends upon variations in climate; that is to say, upon the physical conditions of different regions.

This restriction of certain species to particular areas, by the action of surrounding circumstances, however, gives us no explanation of a still more remarkable phenomenon in the distribution of species, which is, that in different parts of the earth which have climates essentially alike, the species of animals and plants are often very different. There is, for instance, a much greater difference in the species of animals and plants inhabiting the borders of Europe and Asia and those living in corresponding latitudes in the centre of North America, than there is between the climates of the two regions. In like manner, the animals and plants inhabiting South America, South Africa, and Australia, differ far more from each other than do the climates of those countries. We may speak of this distribution of species as the result of *sporadic* (or scattered) *origin.*

It will be necessary to devote a little space to the examination of the principal facts connected with these two kinds, modes, or principles of distribution.

Land and Ocean Climates.—If we ascended from the level of the sea near the equator, up the sides of a lofty mountain to the regions of perpetual snow, we should pass in a few miles through the same variations in climate as if we travelled along the sea level to the arctic or antarctic circles. The variation in the species of animals and plants would also be similar in the two journeys. The difference, indeed, would be chiefly in the rate of change, hundreds of feet vertically, producing an effect equal to that caused by hundreds of miles laterally.

Meyen makes eight vertical botanical regions under the equator, as follows:—

		Height in Feet.
	Region of perpetual snow, with no plants	16,200
1.	Region of Alpine Plants	14,170
2.	Region of Rhododendrons	12,150
3.	Region of Pines	10,140
4.	Region of European Dicotyledonous trees	8,100
5.	Region of Evergreen Dicotyledonous trees	6,120
6.	Region of Myrtles and Laurels	4,050
7.	Region of Tree Ferns and figs	2,020
8.	Region of Palms and Bananas	0

As each of these vertical regions ranges north and south, it descends towards the level of the sea, and forms a zone surrounding the earth; the eighth region forming the equatorial zone, 15° broad on each side of the equator; the seventh, the two tropical zones, each 8° broad; the sixth, the two subtropical, 11° broad; the fifth, the warmer temperate zones, 11° broad; the fourth, the colder temperate zones, 13° broad; the third, the subarctic zones, 8° broad; the second, the arctic, 12° broad; and the first, the polar zones, 12° broad. These zones are bounded, however, by isothermal lines, rather than parallels of latitude, so that the width of some of them varies in different parts.

A similar change of climate takes place as we descend vertically into the sea, and a similar consequent change in the species of animals and plants. This was first clearly shewn by Edward Forbes, during his researches in the Egean Seas. The change as we descend into the sea is, however, modified by the increase of water-pressure being more rapid as we descend into it, than the decrease of atmospheric pressure is in ascending into the air, and by the loss of light in the depths of the sea (light being supposed to cease entirely at 700 feet), to which there is nothing corresponding in the heights of the atmosphere.

Edward Forbes divided all seas into five vertical spaces, which he called zones (not regions), as follows:—

1. Littoral zone, the space between high and low-water mark, or where there is no tide, the water's edge.
2. The circum-littoral zone, from low-water mark down to about 15 fathoms.
3. The median zone, from 15 to about 50 fathoms.
4. The infra-median zone, from 50 to about 100 fathoms.
5. The abyssal zone, from 100 fathoms to the greatest depth to which life could continue to exist.

He likewise arranged marine life into nine homoiozoic belts (or belts of similar life), surrounding the globe, and also bounded by isothermal lines, one central or equatorial, and four on each side of it which he called circum-central, neutral, circum-polar, and polar. Each

of these belts, however, had its vertical zones as above, and did not merely correspond with one of them, like the botanical regions and zones of Meyen.—(*Johnston's Physical Atlas, 2d edition.*)

There is, indeed, a difference even in the distribution of temperature in the two oceans of air and water which surround the earth, arising partly from the difference in their physical constitution, and partly from their limitation in space. The ocean of air that surrounds the earth is interrupted but for very slight spaces near its lower surface, where there happens to be great irregularity in the vertical or relief form of the land on which it rests. The loftiest mountains or table lands penetrate but a short distance up into the atmosphere. The ocean of water, however, not only rests on an irregular base, but is included within a very irregular bed, its free circulation being continually impeded and deflected by large parts of that bed rising completely above it, and forming dry land. Even if we supposed, however, the sea to form as regular an envelope to the earth as the air does, there would nevertheless be a difference in the distribution of their temperatures.

We may regard the distribution of mean temperature in the air, under the figure of shells or regularly arched strata, superimposed one over the other, the hottest surrounding the earth about the equator,* the next spreading over that, and the next over that, and so on, each shell having a less mean temperature than the one underneath it. In fig. 104, let C be the centre of the earth, and the blank semi-

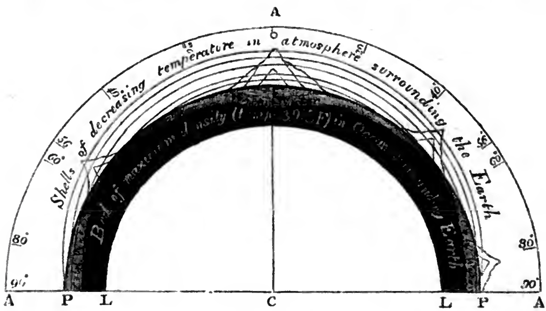


Fig. 104.

circular space over L C L represent a section of half the solid part of the globe. Let the line C E be in the direction of the equator, and

* The equator of heat, *i.e.*, the circumference of greatest mean temperature, does not exactly coincide with the true equator of the earth.

the line P L C L P be the polar axis of the earth, P P being the poles and let the semicircle P E P represent the surface of the supposed uniform ocean of water, the depth of which, P L, is enormously exaggerated. Let the semicircle A A A represent the extreme limits of the atmosphere, quite as much exaggerated in height as the sea is in depth. Then the arched lines over P E P will represent sections of the supposed shells of decreasing temperature in the atmosphere, the hottest being the lowest just over E. The lofty mountain over E will penetrate all these shells, its summit being just in that stratum of cold which in its gradual descent reaches the sea level about the poles.

About the equatorial regions of the earth, or in the neighbourhood of E, the decrease of temperature as we descend into the sea will take place in the same way as it does in ascending into the air. There will, however, be a limit to this decrease in the sea, unlike anything that we know of in the air. Taking the mean temperature of the water at the level of the sea about the equator as 82° Fahrenheit, there will be inverted shells or saucers of cooler and cooler water beneath that till we come down to a depth of about 7200 feet, when we shall have a temperature of about 39.5° Fahrenheit.* This, however, is the temperature of the maximum density of water, and therefore all the water below that depth must be of that same temperature, for if any particle of water below were made either hotter or colder, it would become lighter, and therefore float up to this level. But keeping in mind the figure of saucers or shells of water, it will be apparent that this stratum of 39.5° Fahrenheit, will somewhere rise up to the upper surface of the sea, or *sea level.* This would probably take place about latitudes 56° or 57°, and proceeding towards each pole from those latitudes, there must be saucers of colder and colder water, one upon or inside each other, until the water becomes eventually converted into ice (see fig. 104). In the polar regions, therefore, the temperature of the water will *increase* as we descend (instead of decreasing, as about the equator), until we again come down to the stratum of 39.5° Fahrenheit, which is believed to lie at a depth of about 4500 feet, in latitude 70°.

Such being the normal distribution of mean temperature in the atmosphere and the ocean, let us briefly examine the modifying effects of the various movements caused partly by the orbital motion of the earth with its inclined axis round the sun, and partly by its rotation on that axis.

As the earth rotates on its axis, the atmosphere and the ocean of course move with it.

From the nature of circular motion it is clear that the more distant from the axis of the rotating body any point may be, the greater will be the circle it describes during each rotation. A point on the equator,

* Somerville's Phys. Geogr., chap. xvi. Sir J. Herschell's Meteorology, p. 39.

then, will describe a larger circle during the twenty-four hours than a point on the latitude of 20°, 40°, 60°, or 80°. If a man travelled round the globe on the equator, he would make a journey of nearly 25,000 miles; if he could travel round it along latitude 80°, his journey would be little more than 4300 miles.

Similarly on any given latitude, a point deep in the sea will describe a less circle, and a point high in the air will describe a greater circle than any of the points between them.

It follows that if any body of air or water be moved vertically upwards or downwards, or travel directly towards the equator or the poles (*i.e.*, northwards or southwards), it will have not only that absolute motion, but a relative motion eastwards or westwards consequent on the eastward movement of rotation by the part it arrives at being faster or slower than that of the part it left.

Now the sun's rays are hottest where it is vertical, and they cause a vertical motion in the air beneath it in consequence of the expansion produced in that air by the heat communicated to it, either directly or by contact with the earth, so that the air becomes lighter and floats upwards. Similarly, the water of the sea is made warmer, and therefore lighter, beneath the vertical sun, and a greater portion is removed thence by evaporation from its surface. Air and water, therefore, are both sucked up by the sun to a greater extent where it is vertical than elsewhere. This vertical transference of air and water produces a direct north and south motion in the parts just outside the space sucked up, as they must rush in in order to supply the place of that which is being removed; and these vertical, and direct north or south, movements are partly turned aside in consequence of the rotation of the earth. Thus are produced those currents in the air which are called the trade winds, and the counter westerly winds outside the tropics. And thus the surface of the ocean is set in motion by currents which are only not so regular as the trade winds, in consequence of the interruptions in the circulation of the water arising from the interposition of land. The very motion in the air itself, too, blowing along the surface of the water, contributes towards the production of a current in it.

As the sun is never vertical over the same spot two days in succession, except just at the solstices, but travels backwards and forwards over the central belt of the earth's surface, in consequence of the axis of the earth being inclined to its orbit, it follows that the place where these motions are generated is similarly movable, and oscillates during the year, now on one side and now on the other of the equator.

The irregular distribution of land and water likewise affects the position of the original moving impulse, in consequence of the difference in the heating power of the sun's rays on a land surface and a water surface, and the difference in the respective powers of radiation pos-

sessed by these two surfaces. This cause goes to the extent, in some localities, of setting up local centres of motion in the air, which shift their place according to season, or the place where the sun happens to be vertical, thus producing monsoons, or local periodical winds, instead of trade winds.

The variations in altitude of different parts of the land produce still farther modifications in the air currents.

The complicated machinery thus set in motion over the central regions of the earth causes motion throughout the whole extent of the two oceans of air and water that surround the earth. A regular system of circulation is set up both in the atmosphere and the sea, its regularity being continually interrupted and disturbed by the irregular outline of the land and sea surface, and the irregularities in the *relief-forms* of the land, and to some extent in those of the bed of the ocean.

It thus happens that the climate of any part of the earth's surface, either terrestrial or marine, depending primarily on its latitude and its altitude or depth, is also governed to a great extent by its position with respect to the hot or cold currents of air and water, and also by its proximity or otherwise to neighbouring great irregularities of surface, and the aspect of these irregularities.

The important element of temperature has been graphically represented by means of what are called isothermal lines, pointing out the mean temperature of different places, either for the whole year or for the summer and winter months of the extra-tropical regions. The latter are often more important than the former, since it is obvious that two places may have the same mean annual temperature, and yet possess very different climates. One place, for instance, might have a mean winter temperature of 50° and a summer one of 70°, while another might have a mean winter temperature of 20° and a summer one of 100°, and yet both have a mean annual temperature of 60°.

Various degrees of Climate Influence.—Different species of plants and animals are differently affected by climate, some being, by their constitution, adapted for only one peculiar kind of climate, and perishing if they are moved beyond it, while others, more hardy, will survive, and some even flourish almost equally well, through many different kinds of climate. Man, and his companion the dog, are the animals which withstand best almost any amount of change in this respect.

Food to be included in Climate.—It is obvious that when speaking of the influence of climate on plants or animals, it is necessary to include food in the idea of climate, because if the mere temperature and other circumstances be ever so suitable, they will perish without food. Minerals are the food of plants, together with water and air, which are essential both for themselves, and inasmuch as they dissolve

other substances, and thus prepare them for use. Animals feed either on plants or on other animals. Before plants can exist, then, in any part of the earth, or could come into existence on the earth at all, air containing carbonic acid gas, and water containing dissolved mineral matter, must have existed. In like manner, before plant-eating animals could exist, a sufficient stock of plants for their food must be in existence, and a sufficient stock of plant-eating animals, before other animals lived that were to be supported by feeding upon them.

It must be recollected that this is true of marine and fresh water, as well as of terrestrial beings.

Destruction, partial or entire, of Species of Plants and Animals.—The fact of the adaptation of species of plants and animals to peculiar climates (including food in the idea of climate), involves the necessity of the destruction of species as a consequence of an alteration in climates. If from any physical changes, such as those which we learn from Lyell's Principles of Geology to be taking place continually in some locality or other, sea be converted into land, or land into sea, deep water into shallow, high land into low, or the reverse of those, such changes must involve the destruction of many of the species inhabiting the areas so changed, or of all of them, according to the amount of change. Some of those species may have been limited to the areas thus affected, if so their destruction will be complete, unless they shift their habitation during the progress of the change, and establish themselves in new areas. Both total extinction and local extinction may thus be caused, the latter being the result either of the partial destruction of an inhabited area, or the result of migration from an area totally destroyed.

Another source of destruction is the removal by physical change of a barrier that once existed between the areas of two species, of which one is more powerful than the other, and destructive to it when both are inhabitants of the same area.

One plant may thus outgrow and overwhelm another, or a plant-eating animal may usurp the food of another plant-eating animal, or a flesh-eating species may prey upon, and directly destroy another species of animal, or indirectly destroy it by usurping its food.*

Add to these causes the effects of blights and murrains, or epidemic diseases among plants and animals, and we have enumerated all the most obvious causes of the extinction of species.

It seems to follow from these premises, that if physical causes of

* One species seems sometimes to be animated by pure hostility to another, as in the case of the black and brown rats. The old English or black rat was said at one time to be universal in our islands; whether it ever spread beyond them I am not aware, but the rat which is now common, and called the brown or Norwegian rat, is said to have been introduced, and to have almost entirely extirpated the other. The black rat still exists, however, in some remote corners, as I can answer for its having been the common rat, if not the only rat, in Bantry about the year 1854.

change were left to act for an indefinite time upon the life of the globe without any renovation of that life by the introduction of new species, the whole world would ultimately be tenanted only by the comparatively few more hardy species which could survive all these changes; and it seems also to follow, that wherever two parts of the globe, however distant, had similar climates, we should find in them the same species of animals and plants.

Sporadic origin of Species.—A species of plant or animal apparently consists of the descendants of some one individual, or pair of individuals, that originated on some spot of the earth's surface. These spots are called specific centres, because, as the descendants multiplied, they spread themselves in all directions round them as far as time and climate (that is, all the surrounding circumstances) would allow. These originating spots or centres seem to have been scattered broadcast over the world. Every large area of the world has been found to be fertile in species of animals and plants peculiar to it, and some very small areas, such as little islands remote from any other land, or detached lakes and seas, have in like manner been found to be inhabited by species which did not exist anywhere else.

We cannot escape the conclusion, that either direct creation, or the action of some principle of variation and multiplication of forms has been in frequent or continuous operation in all parts of the globe, both on land and in the water.

Schouw divided the globe into twenty-five botanical regions, in each of which at least one half of the known species, a quarter of the genera, and some individual families, were peculiar to that region, and found nowhere else. These regions are scattered variously over the globe, but they admit, as shewn by Meyen, of an arrangement into zones, each zone surrounding the earth, and including regions in which, although the plants are distinct, yet they are more like and more nearly allied to each other than those of other zones. Not only are the regions of plants in each of these zones similar to each other, but there is another kind of similarity in those of corresponding zones in the opposite hemispheres, so that the plants may be said to be, although entirely distinct, representative of each other.

The evergreen forest trees, for instance, of the northern warmer temperate zone, are represented by other evergreen forest trees in the south warmer temperate zone, each latitudinal zone still having its distinct vertical region of plants, as before described.

Some particular species of plants are confined to very small areas. Small islands, for instance, such as Madeira and Teneriffe, have species of plants which are found nowhere else. I recollect being shewn a violet on the mountain of the Peak of Teneriffe, which was said only to occur on that particular mountain.

In the Canary Islands, generally, out of 533 species of phænogamous plants, 310 are peculiar to them. On St. Helena, out of thirty native species of phænogamous plants, only *one or two* exist in any other part of the globe. In the little archipelago of the Galapagos Islands, there are a hundred species of flowering plants found only in those islands, some only on some of the islands and not on the others. (*Humboldt and Darwin, as quoted by Lyell. Princ.*, chap. xxxviii.)

The same rules hold good in the animal kingdom.

Edward Forbes arranged the marine life of the globe, especially the Fish, Mollusca, and Radiata, into twenty-five provinces, ranging along all the coasts of the globe, each of his Homoiozoic belts containing one, two, or more of these provinces as they sweep round the globe.

Milne Edwards in his Histoire des Crustacées had previously sketched out somewhat similar provinces as inhabited by different groups of species of crustacea, and similar arrangements could be shewn to be practicable with other classes of animals.

The boundaries of these various provinces or regions are sometimes very well marked. This is especially the case wherever any strong natural feature occurs, such as the separation of two land provinces by a chain of inaccessible mountains, or by a narrow and deep sea, or that of two marine provinces by a narrow neck of land, or the meeting of a warm and cold current of water. At other times adjacent provinces may be more or less blended into each other, so that it is difficult to say where one ends and the other begins.

M. Barrande, in his "Parallèle entre les depôts Siluriens de Bohême et de Scandinavie," has some very instructive remarks on the close approximation of widely distinct marine provinces. Wherever two spaces of sea are separated by a narrow neck of land, uniting countries which stretch far and without interruption through different climates, we may have totally different species within a few miles of each other. This happens at present in the instances of the Isthmus of Suez and Isthmus of Darien.

In the first case, according to the best authorities, there are no species of Fish or Crustacea common to the Red Sea and the Mediterranean, with the exception of a few cosmopolitan species ; neither are there any species of Molluscs common to the two seas, with a few doubtful exceptions ; while with regard to the Zoophytes, this is true without any exception at all.

In the second case, on the authority of M. Alcide D'Orbigny, there are 110 genera of Mollusca on the two coasts of South America, of which fifty-five are common to the Pacific and Atlantic Oceans ; thirty-four peculiar to the Pacific, and twenty-one peculiar to the Atlantic. There is, therefore, a generic correspondence to the extent of one half ; that half being probably the most important, and containing the greatest

number both of species and individuals. But these 110 genera contain 628 species, and of these *one only* is to be found common to the Atlantic and Pacific Oceans.

Examples of the Geographical Limitation of Animals as proving their Sporadic Origin.—In order not to leave the reader with mere dry abstract generalizations, it may be advisable to mention a few of the best known and most marked examples of the limitation of certain species and genera of animals.

a, *Fish.*—The sea-fish vary greatly in different parts of the world. The cod, the turbot, and the sole are peculiar to the Arctic seas and the adjacent parts of the Atlantic. The salmon accompanies them, but runs down the western coast of North America as far as the Columbia River, while in Europe it is never found, I believe, in any river running into the Mediterranean or Black Sea. The tunny and other Mediterranean fish are in like manner unknown in the Atlantic.

The fresh-water fish are equally limited in some parts of the world. In New South Wales, the large cod-perch, as it is called, is found only in the rivers running down the western side of the eastern coast range, and not on the eastern side of that range.

b, *Birds.*—Perhaps the most striking facts of limitation of species, however, are those occurring among birds; whose powers of easy and rapid locomotion seem to place the whole world at their disposal.

Some birds do range over very large parts of the earth, but others are limited to the smallest territories. The red grouse of our own islands is not known to exist in any other portion of the earth. The nightingale, which visits the south-east of England during the summer, and abounds then in Cambridgeshire, and extends even to Northampton, stops at a certain line, running thence down into Dorsetshire, and is never heard to the north-west of that line.

Perhaps there is no more striking instance of the restriction of species to narrow limits than that observed by Mr. Darwin in the Galapagos, and described in his Naturalist's Journal. Here we have a small cluster of islands all volcanic, and all therefore of the same character, and all nearly under the equator, and therefore enjoying the same climate, and yet not only have they a fauna and flora distinct from that of the rest of the world, but different species are found in the different islands, making the group into a little world of its own, a satellite, as it were, of the great American continent. The animals and plants bear the American stamp, resembling those of America more than those of any other part of the world; they are, however, specifically and even generically distinct. The islands contained no mammal except one small mouse, but numerous reptiles, snakes, lizards, and tortoises, some of the lizards being marine, and the only living species of their class that inhabit the sea, and the large land tortoises being also of very

peculiar forms. Among twenty-six species of land birds, only one is known elsewhere, and some even of these were absolutely confined to particular islands, although some of those islands were within sight of each other.—(*Darwin's Naturalist's Journal.*)

Returning for another instance to Australia, we find that there are peculiar species of parroquet and other birds in Victoria, South Australia, and Swan River, differing from each other and from those of New South Wales, while many of the latter range along the whole stretch of the eastern coast, from 40° S. lat. to within 10° or 12° of the equator. The same species in this case seem to cling to one range of high land, even though stretching through different climates, while they do not cross the intervening plains on to other mountain ranges, although they are in the same latitudes, and enjoy the same climates as the eastern coast range.

The Dodo that inhabited the Mauritius, and was exterminated by the Dutch, and the large and beautiful Norfolk Island and Philip Island parrots, each confined to its little spot of earth, and exterminated by the English convicts, are conspicuous instances of the restriction of large birds to small spaces, and their consequent extinction on the introduction of the hostile species—man.

The humming-birds afford excellent examples both of great range in some species, and of close restriction in others. Humming-birds are peculiar to the American continent, they are found over the whole of it from Cape Horn to Russian America. A small blazing red species (called Salasporus rufus), ranges from Mexico to Sitka. On the other hand, the one called Oreotrochilus Chimborazo is only found on the mountain from which it takes its name, and only between the altitudes of 12,000 feet and 15,000 feet above the sea, another called Oreotrochilus Pichincha is only found between the altitudes of 10,000 and 14,000 feet upon Pichinca. Ereocnemus Derbianus has never been found except in the crater of the volcano of Puraci.—(*From information communicated by Mr. Gould.*)

The ostriches and their allies are equally remarkable as exhibiting the organization of different species of birds, all unable to fly, in so many different parts of the earth. The ostrich proper (*Struthio camelus*) inhabits Africa and Arabia. In south America there are two species of ostrich, one (*Rhea Americana*) inhabiting the eastern plains north of the Rio Negro, the other (*Rhea Darwinii*) the plains of Patagonia. In Australia we have the Emeu (*Dromaius novæ Hollandiæ*), in New Guinea and the neighbouring islands the Cassowary (*Casuarius galeatus*), and another species from New Britain, and in New Zealand the *Apteryx* and the recently exterminated *Dinornis*, of which Owen says there must have been twelve species. There was another bird also (called *Æpyronis*) in Madagascar, now known chiefly by its eggs, one of which

would have held 148 eggs of the common fowl. (*Owen's address to the Brit. Assoc. at the Leeds Meeting.*)

It is impossible, as Owen remarks, to suppose that all these different species of birds that can neither fly nor swim, nor endure severe climates, could have sprung from one common Asiatic centre, according to the generally received hypothesis of the origin of species. It is also equally difficult to understand why that strange anomaly, a bird unable to fly, should have been developed by any physiological law, such as Darwin's doctrine of variation, in so many independent localities, though that objection might perhaps be met by the supposition of the gradual breaking up and separation of once continuous land, so that a non-flying bird once produced, might afterwards vary into many different kinds of non-flying birds in the different separated areas derived from, or from time to time connected with, the original area.

As a contrast to birds that cannot fly at all, we may instance many oceanic birds who seem to pass their lives upon the wing, and yet never or very rarely overstep certain limits. In the south Indian Ocean, between the Cape of Good Hope and Australia, the sea is always alive with birds south of latitude 31° or 32°, while to the north of that line none are seen except an occasional tropic or frigate bird. Towards the south flocks of albatrosses and cape pigeons seem as if always accompanying the vessel in its course, the cape pigeons always busy about the ship, while the great albatross (*Diomedea exulans*), and the still more numerous dusky species (*D. fuliginosa*) ever sweep in steady curves between the ship and the horizon, now sailing close by the rigging and eyeing the persons standing on the poop and then gliding out of sight ahead, as if the vessel were at anchor. If, however, the ship turn towards the north and pass the limit mentioned above, all these hosts of birds disappear at once, nor are they ever seen again till the navigator return to the south when he finds fresh flocks as if awaiting his arrival.

c, *Mammalia.*—We find similar restrictions as to the areas inhabited by species or groups of species among the highest class of animals, namely, the mammalia. In the Arctic regions, indeed, we find many animals, such as the musk ox, the polar bear, and the night northern whale, and others, both terrestial and marine, common to the whole circle. But as we travel south, and the lands and seas begin to diverge from each other, the animals, even in corresponding latitudes and similar climates, soon become diverse. The black and grizzly bears are American only, the brown bear is an old world inhabitant only. Still farther south, the puma and jaguar of America represent, but are very different from, the lion and the leopard of the Old World. The camels and dromedaries of the Old World are similarly represented by the llamas and guanacoes of the New; and each great division of the globe is inhabited by many different species of deer and other corresponding animals. The monkeys

may be divided into three groups, the Catarhini, belonging to the old world, the Platyrhini, to the new, and the Strepsirhini, most of which belong to Madagascar.

There are, however, many groups of animals wholly confined to one of the great divisions of land.

No true pig (Sus) was a native of America, the peccaries (Dicotyles) are American only. There are now no representatives in the American continent of the elephants, rhinoceroses, hippopotami, or giraffes of the Old World, while the sloths (*Bradypus*), the anteaters (*Myrmecophagus*), and the armadillos (*Dasypus*), are not met with out of America. There is indeed a pangolin (*Manis*) in Africa, and another in Asia, and an *Orycteropus* in Africa, otherwise the whole order of Edentata would be entirely American.

There is, however, a still closer restriction among the species of each of these animals. One species of elephant is peculiar to Africa, and another to India, and perhaps a third to Ceylon and Sumatra. There are three species of double-horned rhinoceroses in South Africa, and one in the island of Sumatra, Java having another with only one horn. There are different species of sloths, anteaters, and armadillos in different regions of South America.

The Marsupial animals are now confined to Australasia, with the exception of one genus, the didelphys or true opossum, which is American only, some of its species being restricted to very narrow limits. In Australasia the Marsupials of New Guinea are entirely and some of them widely distinct from those of Australia proper, and in Australia itself the kangaroos and wallibis, and phalangers are different in different parts of the country. Mr. Gilbert, who was collecting for Mr. Gould, and unfortunately lost his life in Dr. Leichardt's first expedition, informed me, when I met him at Swan River, that with the exception of the Echidna, or so called Australian porcupine, he had not been able to find a single animal or a single bird among all those he had collected in Western Australia that was identically the same as any in New South Wales. The lesser island of Tasmania has the two largest and most powerful carnivorous Marsupials absolutely peculiar to it, those, namely, which are called the Native Tiger (Thylacinus cynocephalus), and the Devil (Sarcophilus (Dasyurus) ursinus).

That strange animal, the duck-billed Platypus, or Ornithorhynchus paradoxus, appears to be confined entirely to the south-eastern corner of Australia.—*See Owen's Presidential Address, previously cited, Johnston's Physical Atlas*, etc., etc., etc.)

Generic Centres and Districts.—That any one species should be confined within certain limits round its point of origin seems natural or inevitable as the direct result of the action of climate, or the physical limitation of the land or water area in which it came into existence.

It is, however, very worthy of notice, that those groups of allied species, which we call genera, are equally circumscribed.

Why should different species of opossum (*Didelphys*) have originated in America, side by side with each other, and nowhere else? Why should different species of kangaroo (*Macropus*), and other marsupial genera have originated in Australia or Australasia, and in no other part of the world?

If the limits of a species be the natural result of the descent of the individuals composing it from a common mother, does not the limitation of a genus point equally to descent from a common species? The same question might be asked as to the limitation of the different genera comprising a family or order, making allowance for the obvious condition that the larger the group of species (genus, family or order) the larger is the area likely to be occupied by it, and its limitation will become therefore less and less obvious. The fact, however, that genera (of whatever extent) are geographically limited, is one that is provable by many examples both among plants and animals. Edward Forbes insisted on it strongly, and pointed out that genera had their *centres* where their *species* were most numerous and flourishing, in the same way that *species* had their centres where the *individuals* flourished best, and that receding from those centres, both vertically and laterally, individuals in the one case, and species in the other, gradually faded away till at certain limits they ceased to exist.

These facts are highly suggestive when we come to speculate on the origin of the various forms of life upon the globe. They seem, in connection with the geological history of some species and genera, to have originated in Charles Darwin's mind those speculations of which we have already received the first fruits in his highly philosophical and original work on the "Origin of Species."

Breaking up of Generic and Specific Areas by Geological changes.—Certain facts in distribution at the present day which seem to militate against the truth of the limitation of genera (and perhaps of species also), are easily explained when we learn their geological history. Edward Forbes, for instance, pointed out that the genus Mitra has at the present day its centre in his central homoiozoic belt, its area extending thence through the two circumcentral and into the south neutral belt, but that one outlying species, Mitra Greenlandica was found in the north polar belt. This detached species, which seemed to form so striking an exception to the doctrine of continuous generic areas, is, however, known to have once formed part of the great generic area of Mitra, inasmuch as Mitræ of other species formerly existed in the intermediate space. The extinction of these species of Mitra has broken up the once continuous area; and it is probable that the many physical changes that have taken place, and the mutations between

land and sea, and height and depth of either, have in many instances broken up generic and specific areas, and either contributed to their dispersion, or perhaps in some cases aided in restricting them within still narrower limits.

A little consideration will shew that if the individuals of a species, or the species of a genus, be rare, and their limits narrow, it may be either in consequence of their being new, only just beginning to make their way in the world, or because they are old and dying out. If they be found in two or three localities widely apart, the latter is almost certainly the true state of the case. There is a genus of fresh-water fish called Coregonus, the porran of Cumberland, the pollan of Lough Neagh, the Gwynniad (or white fish) of Bala Lake, the white fish (or freshwater herring) of the North American lakes, other species being found in the Siberian rivers. Some of the North American and Siberian species are very abundant in their several localities (see *Richardson's Polar Regions*), but those of the British lakes are rare fish, only occurring in the detached lakes mentioned above, and only to be seen at particular seasons even in them. They are, doubtless, remnants of those which, when the arctic climates of North Siberia and America extended over the British islands and the whole northern area of the world, were equally abundant over the whole of that area, and are now approaching extinction in different isolated localities of the area where arctic climates no longer prevail.

The geological bearings of the facts of the geographical distribution of organic beings at the present time now become apparent, and two other instances may be briefly given.

It is said that the existing fauna and flora of North America have remarkable generic and ordinal analogies with those which prevailed in Europe during a recent tertiary age. There is perhaps a closer relation between those recently extinct European genera of animals and plants and the existing North American ones, than there is between the latter and the present European genera. It is possible, therefore, that the present European fauna and flora may be of more recent date than those of North America; that genera and species, once common to the two continents, have remained less changed in North America than in Europe, where they have become extinct by some of the actions previously alluded to, and have been replaced by other forms. The climate of North America has probably been less altered since the glacial period than that of Europe has.

Another set of facts is still more remarkable. The animals and plants of Australia are very peculiar, and many of them such as are found nowhere else living in the world. Now, some of the marine shells and some of the land animals and plants more resemble those found fossil in rocks deposited during an early geological period (the

Oolitic) in our part of the world, than they do any other ordinal or generic types. It is possible, therefore, that the fauna and flora of Australia are, as it were, the remnant of that which, during the Oolitic period, was common to the whole globe, but which has everywhere else been superseded by the introduction of new generic and ordinal forms.

CHAPTER XXIV.

THE LAWS AND GENERALISATIONS OF PALÆONTOLOGY.

The Kinds of Animals and Plants most likely to occur Fossil.—The rocks in which organic remains are found are aqueous rocks, principally marine. We should, therefore, naturally expect the inclosed fossils to be the remains of aquatic, principally marine, beings. In the vegetable kingdom, at the present day, the vast majority of the species are terrestrial, while in the animal kingdom there is an almost equal majority of aquatic species. Among the Vertebrata, for instance, we have two orders of Mammalia entirely aquatic, a large part of the Reptiles and Amphibia, and the whole of the Fish. In the sub-kingdom Annulosa, the insects, indeed, like the birds among the Vertebrata, are chiefly terrestrial or aerial; but the Crustacea are chiefly, and the Echinodermata entirely, aquatic. The exceptions to the aquatic character of the rest of the whole animal kingdom, including the Mollusca and the other sub-kingdoms, are very few and comparatively unimportant, the Pulmonata, or land snails, being the principal one.

This at once gives us a reason for the fact of the remains of animals being more numerous than those of plants, and of aquatic animals than those living on land. Even where they occur in equal abundance, animal remains are more important than vegetable, inasmuch as it is more easy to arrive at definite conclusions as to the nature and the habits of the once living beings from the examination of a fragment of an animal than from that of a plant. A single scale, or tooth, or fragment of bone, or shell, will often reveal to the comparative anatomist the whole history of an animal which he certainly never saw, and of which, perhaps, the only known traces may be that solitary fragment. The botanist is not in equally favourable circumstances for determining the history of a fossil plant, since a piece of a stem or a leaf will rarely do more than enable him to determine which great division of the vegetable kingdom the living plant belonged to; while the parts, such as the flower, on which he mainly depends for more exact determination, are scarcely ever preserved in a fossil state.

It is to the terrestrial animals, as most important to us economically, and most frequently before our eyes, that we are naturally accustomed to look as our fellow-inhabitants of the globe, but in reality, if

we except the terrestrial Mammalia, the Birds and the Insects, almost all the infinite variety and abundance of other animals live in the water. We should therefore naturally expect to find, as we do, portions of all the other kinds of the animal kingdom in great plenty, while remains of Mammalia, of Insects, and of Birds, must be comparatively rare.

It is necessary to take these considerations strictly into account before we found any reasoning upon the negative evidence of the absence of terrestrial animals or plants in a fossil state.

Very important conclusions are doubtless to be drawn from the study of the terrestrial kinds when they do occur fossil; but even then their practical value to the geologist is often small, on account of their rarity. Many of the extinct species and genera of Mammalia, for instance, are founded upon the occurrence of single fragmentary specimens, or of not more than two or three specimens; fossil Fish are more numerous, but the testaceous (or shell-bearing) Molluscs, the Crustacea, the Echinodermata, and the Corals, occur by hundreds and thousands, mountainous masses of rock being in some cases made up of them.

We might accordingly take any one of these last mentioned, and compare the different assemblages of them found fossil in different formations, with the expectation of arriving at some definite conclusion as to their history. Of all fossils, however, the Mollusca afford to the palæontologist the most complete and unbroken scale of comparison on account of their number, their variety, and the comparative completeness of the preservation of their fossil parts, and the consequent facility of determining their nature and habits.

Number of British Fossil Animals and Plants compared with existing British Species.—The British Islands are included within the Celtic province of Edward Forbes; and considering the diversity in the forms of the land and the distribution of land and water, the variety of "station," and of the climate and surrounding circumstances, we may assume that they afford us a fair example of what the terrestrial, fresh-water, and marine fauna and flora of a province ought to be. They contain, perhaps, as great an abundance of species as any other region of equal extent, out of the tropics, and more than many equal-sized districts within them.

In the following table I have been assisted by my friend and colleague Dr. Kinahan in stating the numbers of living* species. The numbers of fossil animals and plants are those given by Professor Morris in his *Catalogue of British Fossils*, a book which every working geologist knows to be *indispensable* to his labours.

* It is possible that the opinion of naturalists might differ as to the precise numbers stated in this table, but the difference would not greatly affect the conclusions drawn from it. It would matter little to the argument whether the true proportion between the living and extinct British testaceous Mollusca be 1 : 8 or 1 : 9 or 1 : 10.

LIVING AND FOSSIL SPECIES OF THE BRITISH ISLANDS.

	No. of Species Living.	No. of Fossil Species.	Proportion of Living to Fossil.
Plants	1600 flowering. 2800 cryptogamic. 4400	655	670 : 100
Zoophytes*	70	435	100 : 620
Polyzoa	70	258	100 : 370
Testacea†	513	4590	100 : 890
Echinodermata	70	492	100 : 700
Crustacea‡	225	298	100 : 130
Fishes	162	741	100 : 460
Reptiles	18	180	100 : 1000
Birds	332	11	3000 : 100
Mammals	70	110§	100 : 157

Perhaps the most unexpected result of the preceding table is that the extinct fossil Mammalia of the British Islands are *more numerous in species by one-half* than the existing Mammals. This at once prepares us for the belief that if our present fauna is a good example of what the population of a province ought to be, the fossil fauna must represent more than one such population.

If we turn to the Testacea as our best guide, we find that the fossil species known are nearly nine times as numerous as the living species. If, indeed, we excluded the land and fresh-water shells from each side of the comparison, we should find the fossil marine testaceous Mollusca *more than ten times the number* of the living ones. Our conclusion must be, that there are buried in the British Islands the remains of *at least ten* complete populations of Mollusca, each as numerous in species as those now living in the seas around us. But as a matter of fact, while the existing population is almost entirely known from recent most elaborate researches, the extinct populations are yet very imperfectly known; and some great groups and formations exist in which few or no fossil Mollusca have yet been found; and therefore we may feel assured that the number of fossil Mollusca are in reality the represen-

* Principally Corals, as they are commonly called.

† Under Testacea, all the shell-bearing Molluscs are included.

‡ Under the living Crustacea, the Cirripedia are not included. (Proximate only, probably 300 species are known.)

§ Morris gives only 96; the new discoveries raise the number to 108, or 110 at least.

tatives, more or less imperfect, of much *more than ten* populations of the past which have died away and become extinct.

This conclusion is confirmed by examining the other classes of aquatic animals, the fossil Fish for instance are nearly five times, the Echinodermata seven times, the Zoophytes more than six times, and the Reptiles ten times more numerous than our living ones, most of these classes having been still more partially, and, as it were, capriciously, preserved than the Mollusca.

The Modes of Occurrence of Fossils.—Organic remains may be either included in the aqueous rocks in the very spot where they lived, or close to it, or may have been floated or drifted by the water to some distant spot after death, or swept into the water from the land. Any remains floating for some distance in water, and slowly sinking to the bottom of it, or drifted for any distance along the bottom, will give us no information as to the habits or "station" of the species when living. We may get fragments of land plants or animals included in beds deposited in deep sea at a distance from shore, or fragments of animals that lived in clear water deposited in mud or silt, or of animals that lived in sand or mud inclosed in limestone formed in clear water. These, however, are the exceptions rather than the rule, and in the majority of instances the fossils found in rocks lived on, or close to, the spot where they were buried, so that in pure limestone we get the remains of animals that lived in clear water, while in sandstones and clays we get the shells and other animals that preferred to live in or on sandy and muddy bottoms.

Hence when we examine any group of aqueous rocks, that is made up partly of calcareous, and partly of arenaceous and argillaceous rocks, we should expect to find a difference in the fossils according to the difference in the nature of the rock. Fossils are in general much more numerous in limestone than in any other kinds of rock, because limestone is chiefly derived from the remains of animals; but certain kinds of fossils, even certain species of shells, are found mostly in sandstone, others mostly in mud or clay. Land plants and other terrestrial productions are found much more frequently in arenaceous and argillaceous rocks, because these are more usually deposited near the land than calcareous rocks are.

These general statements must of course be taken as mere generalizations, admitting of many exceptions, and must not be construed into absolute rules rigorously governing particular cases. Allowing, then, for exceptions arising both from the drifting of organic remains before they are buried, and from abnormal variations in the deposition of different kinds of rock-material, we shall find, in each group of rocks, limestone fossils, and sandstone and clay fossils.

A series of groups of beds, then, will contain different fossils in

different parts, the difference arising from two different sets of circumstances, viz.—

1st, In consequence of a change in the nature of the rock, or a difference of station at any one period of time;

2d, In consequence of a change in the species of the organic beings, during the lapse of time as we pass from one great period to another.

We may represent this law of the distribution of fossils by the following diagram:—

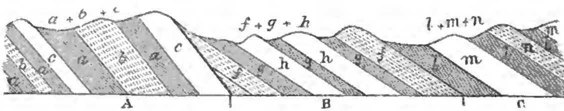


Fig. 105.

Let fig. 105 represent a section through a great series of rocks made up of alternations of argillaceous rocks represented by lines, arenaceous rocks represented by dots, and calcareous rocks represented by the plain bands. Let the series be divisible into three groups, A, B, C; then in the lower group A, we may find certain fossils peculiar to the argillaceous beds, let us call those fossils the *a* assemblage, certain others peculiar to the arenaceous beds let us call those *b*, and others to the calcareous which we may call *c*.

Throughout that group of rocks these peculiar assemblages of fossils may recur wherever we get the peculiar kind of rock. The *a* fossils in the lowest set of clay beds will be replaced by the *b* fossils in the sandy beds above them, but the *a* fossils would recur when we examined the next superior set of clay beds. If over those we met with a set of limestone beds, we should find the *c* fossils in them; and so as we crossed the successive outcrops of the beds, and came to others similar in lithological character to those we had left, we should find similar fossils recurring, the *a* fossils in the argillaceous beds, the *b* fossils in the arenaceous, and the *c* fossils in the calcareous. This change in the assemblages of fossils might take place equally, whether the change in the nature of the rocks took place laterally as they ranged across a country, or vertically as the beds succeeded each other in order of superposition. We should then include the whole assemblages $a + b + c$, when we spoke of the fossils that were peculiar to the whole group of rocks A.

There might also very possibly be a certain mixture of fossils throughout, or certain species might range throughout, independent of those which were peculiar to the different kinds of rock.

When we passed beyond the limits of the group A into that of group B, we should then find an assemblage of fossils of altogether a

different kind. Group B might equally be made up of sets of argillaceous, arenaceous, and calcareous rocks ; and each of these sets might contain peculiar assemblages of fossils, which recurred in any part of the group whenever the peculiar kind of rock recurred. Moreover, there might be little or no difference between the clayey rocks of group B and those of group A, and the sandstones and limestones of each might be equally similar, so that no one could distinguish between the beds of group B and those of group A, by any difference in the nature of the rocks. The fossils, however, might be so dissimilar that the two groups might not have a single species in common ; or the common species would at all events be a very small proportion of the whole. The limestones of B would have an assemblage of fossils we may call h, its clays one we may call g, and its sands one we may call f; and the total assemblage $f + g + h$, together perhaps with others common to the whole, would be the peculiar fossils of the group B.

Similarly the group C might have its argillaceous fossils l, its calcareous or limestone fossils m, and its sandstone fossils n, each recurring in different parts of the group according as the kinds of rock recurred, the whole assemblage $l + m + n$ being the peculiar fossils of C.

The student must not expect to find, in any district, formations containing such a frequent recurrence of different kinds of rock all fossiliferous, as we have supposed in the diagram, and each assemblage, either of the smaller single groups, or of their triplicate unions, so neatly distinguished from each other as is here represented.

Sufficient examples, however, could be easily adduced to shew the tendency of natural operations towards such a state of things, and that if circumstances had allowed of the production of alternating groups of beds all containing the remains of the animals that lived during the periods, on the different kinds of sea bottom, we should then have had a series exactly answering to the one supposed above.

This would have been the case indeed throughout the whole series of stratified rocks, if it had been possible for deposition of beds and entombment and preservation of organic remains to have been continuous. It has, however, been already remarked that the deposition of the materials of rock is, and has always been, the exception, not the rule, and that all our beds of rock were formed at intervals with long pauses of non-production between them. When we add to that the fact that the entombment and preservation of organic remains, especially in clays and sands, must have been an equally exceptional act, and that our series of fossils contains but a few scattered fragments of the vast series of forms of life that have inhabited the globe, we shall feel at once that we can glean from them only a few faint sketches of the laws which have governed the distribution of these forms, and not

look for a perfection and completeness of evidence which the nature of the case renders impossible.

The Geographical Distribution of Species in past time.—When geologists first learnt that groups of rock beds were very widely spread over large areas, and occurred in a certain order of superposition within those areas, and gave names to these groups derived from their lithological character, such as "the Chalk" "the Oolite," "the Mountain Limestone," "the New or Old Red Sandstone," they naturally were inclined to extend the boundaries of these groups of rock indefinitely, and to suppose that the very same kinds of rock would be found in the same order of superposition in all parts of the earth. Travellers did not hesitate to speak of the groups of rock which they found in new countries by these names, trusting simply to the nature of the rock for their identification.

In like manner, when more notice was taken of the fossils contained in these "formations," and observers looked to them rather than to mineral characters, for their identification of a formation, they were at first naturally inclined to conclude that these fossils would be common to the same formation all over the earth.

There is certainly a much closer resemblance in the organic remains found in distant parts of the same formation than there is in its lithological characters, nevertheless there is in many cases a difference in their species which is due to the influence partly, perhaps, of difference in climate, but chiefly to the fact of the sporadic origin and consequent geographical limitation of species.

Even in the earliest periods of the earth's history which we know anything about, the species of the genera or orders which existed in those times were evidently limited to certain provinces, as species are now. Different species having come into existence at certain spots in different parts of the earth, the individuals of those species spread around their centres so far as "climate" (*i.e.*, all surrounding circumstances including food), allowed of their diffusion.

As climate is so much modified by the distribution of land and sea, and of high and low land, shallow and deep sea, and the variation in the currents of air and water, it follows that since the places of land and sea have been continually changing, the climates of different parts of the earth must have been frequently modified, and we know from facts which will be hereafter described, that the climate of the whole earth has also varied. The position, the size, and the number of biological provinces then may have varied very greatly at different periods of the earth's history.

There may have been formerly only a few large provinces like that of the Indo-Pacific ocean of the present day. This may especially have been the case if the climate of the earth generally were once more

equable than it is now, with less cold in the polar regions, and possibly no higher temperature within the tropics than is felt in the equatorial islands of our own times.

Under such circumstances it is obviously likely that in former times the cosmopolitan species, or those which ranged over the whole earth, may have been more numerous than they are now. Still, however the examples of the rule may have varied from time to time, it is very important to note that the law of the geographical limitation of species, both laterally and vertically, has always prevailed.

In examining, therefore, the distribution of fossils in different parts of the earth's crust, we must bear in mind that there are three causes of change in them :—

1. First of all, within the same biological province there may have been differences in the " stations," to use the naturalists' phrase, that is, the place where the fossil was buried may have been at the time either sea or fresh-water, deep or shallow water, near shore or far from it, having a muddy or a sandy bottom, or being a sea clear of sediment, and the fossils entombed at these different stations of the province may have varied accordingly.

2. Secondly, we may pass from one " province" into another, the two provinces having been inhabited by different but contemporaneous groups of species.

3. Thirdly, there may have been a difference in " time," during which a general change had taken place in the species, those formerly existing having become extinct, and others having come into existence that had not previously appeared on the globe.

Difficulty in determining the Contemporaneity of Distant Formations.—It has been stated in the preceding chapter, that a change in the physical circumstances of a district may cause either a local or a total extinction of species, according to the rate and amount of the change. If the change operate slowly and gradually, the individuals of the species may have had time to travel with it, and to settle themselves in a new area, even as a consequence of the change. Moreover, if any species, originating in a certain spot, become subsequently cosmopolitan, or very widely spread, this diffusion may require a vast period of time, so that, even if the existence of the species be of equal length at different parts of the globe, the dates of its commencement and extinction may have been widely different in those parts. It may have even become extinct in its original centre before it reaches some of the more distant parts of the whole area occupied by it.

The fact of particular species, then, being common to the rocks of two distant localities, is by no means a proof of their being *exactly contemporaneous* in point of time. It may prove the very reverse of this. Strict contemporaneity in the rocks of distant localities is pro-

bably a very rare occurrence, and one which would be very difficult to prove. In speaking of the contemporaneous rocks, therefore, of two localities, the student must be prepared for a sufficiently lax use of the term to include great periods of time. Beds deposited in the English Channel before the Romans visited Britain, would be looked upon by future geologists as strictly contemporaneous with beds forming now in the Irish Sea, should the two districts become dry land ; and past dates, separated by actual periods far more vast than any included within historic times, would be equally looked upon now as contemporaneous ; the length of time thus uncertainly determined increasing probably with the distance between the two localities where the rocks were observed.

These principles have always influenced me from my earliest geological days. In speaking of the Coal-measures of Newfoundland, in my report* on the geology of that country, I limited myself to calling them the *Newfoundland Coal-measures,* leaving their identity, or otherwise, with the Coal-measures of other districts, an open question. Not having found any fossils in them in my necessarily hasty search, the Newfoundland Coal-measures might be Tertiary rocks for anything I could say to the contrary. Similarly, in speaking of the Palæozoic rocks and fossils of Australia, I preferred always to speak of them only as Palæozoic, and forbore to discuss the question of their identity in time with the Silurian, Devonian, or Carboniferous periods of Europe, for which even the identity of one or two species (if it occur) is not altogether sufficient evidence.†

Barrande's Colonies.—As a corollary of the principles just now stated may be mentioned M. Barrande's doctrine of Colonies, one of the very curious and remarkable results of his labours in the Silurian district of Bohemia. If two neighbouring but distinct faunas, A and B, contemporaneous, or A a little the oldest, be separated by some barrier, physical, climatal, or depending on other geographical conditions, and a breach be at one time effected in this barrier, or a temporary alteration take place in the conditions, some individuals of the fauna B may spread over part of the province of A ; but circumstances not then favouring their retention of these new settlements, these colonists may die and leave a small band of their remains intercalated between beds containing only the remains of A. At some future period, perhaps, circumstances may favour their extension far and wide into the province of A, and become unfavourable to the existence of that fauna, which will therefore become extinct, and the higher rocks deposited will become filled with the remains of B only.

* General Report of the Geological Survey of Newfoundland during the years 1839 and 1840. Murray, 1842.

† See Sketch of Physical Structure of Australia (Boone), pp. 21, 22.

The little band, containing some of the fossil forms of the B fauna, is spoken of by M. Barrande as a "colony." It is apparently a very unusual occurrence, not having yet been described by any other person than M. Barrande, nor having been met with by him except in Bohemia. His descriptions there, however, have been confirmed by Sir C. Lyell, and it is possible that some similar circumstance takes place in other districts, and has not yet been recognised, and that some of the difficulties in classification occasionally met with may arise from it.

These difficulties, and the others arising from change of rock and change of province, are always of a minor character, affecting the determination of small groups of rock only, or raising doubts as to which of the great classes of rock some particular local group is to be included in, although there may be no doubt as to the great classes themselves.

Necessity for settling the Chronological Classification of each large Area separately, before forming one for the whole Earth.—It follows, from what has been stated, that in order to avoid error, each great district of the earth, such as Europe or North America, should be surveyed separately, without reference to anything out of the district, and that the order of superposition of its strata, and their classification into groups or formations, should be settled independently, on evidence to be found in that district only.

When this has been done, the two series may then be compared, and the synchronism of different parts of each may be decided on.

Western Europe (Britain, France, and Germany), but England more especially above all other countries of the world, affords the best type of a geological district from the examination of which a chronological scale of classification can be constructed with which to compare the series of rocks in other parts of the world. Care must however always be taken, that this comparison with British or European formations be not pushed too far, until the district to be compared has been worked out thoroughly on its own independent evidence.

The British scale of rocks, although the most complete anywhere yet known within any one district of anything like equal extent, must not therefore be assumed to be perfect, or to be absolutely, instead of comparatively, complete. The series of formations even in Britain is full of gaps, which are known and acknowledged; those which are still unsuspected are probably still more numerous.

Many of the formations, or groups of stratified rocks in other parts of the world, which were at one time thought to be contemporaneous with British formations, are now known, or believed, to be more or less intermediate between them. This intercalation of periods of formation in different parts of the earth, and even in different parts of the same district, will probably have to be still more extensively employed hereafter.

Classification of Groups of Beds by means of their Fossil Contents.—If we take the British Islands or any other good typical portion of the earth's surface, and examine, as far as we can, its subterranean structure, we shall find that it is made up of a vast series of variously inclined strata, which appear at the surface in consequence of their "rising" or "cropping" out, one from under another, the former extension of each having been removed by the denudation which produced the surface.

This great series is not made of a continuous succession of beds, neither are the beds all of one kind. The lines of discontinuity, and the changes in the lithological characters of the beds, have afforded geologists the means of separating the great series into groups, to which names have been given. Most of these groups contain fossils, some of them most abundantly, large parts of them even consisting entirely of organic remains. It is obvious that in such a series of groups of stratified rocks rising out one from under the other, the lowest must be the oldest or first formed, and that as they were deposited in succession one over the other, the newest must be the uppermost.

Now it has been discovered that each of these great groups has an assemblage of fossils peculiar to it; so that the fossils found in one group are not found in any other group.

Particular species of fossils seem occasionally to range into two, or perhaps even three adjacent groups, occurring perhaps in the upper part of one group, ranging through the whole of the group above it, and appearing in the lower part of the group above that. Some species, on the other hand, are found only in a very small part of one group, either throughout the lateral extension of the beds wherever they occur, or sometimes limited to some small locality in those beds.

What is true of individual species is true also, with a more general and wider application, of the genera and families into which those species are grouped for classification.

When a single species occurs abundantly in one or two beds, throughout the extension of those beds, we may, if we find it convenient, make a subgroup of those beds, and give them a distinct name, taking the occurrence of the species as the characteristic of the beds.

Such a small set of beds, whether its characteristics be thus palæontological or merely lithological, is often very useful as giving us a "horizon," and enabling us to determine which are the beds above and below it *wherever* we find a portion of the set exposed.

When a single species, or an assemblage of several species, occur in a group of rocks, whether large or small, and have never been found except in that group of rocks, and are almost always found wherever the group extends, we may speak of those as the *characteristic species* of the group.

It occasionally happens that the fossils of such a group are so nearly

allied biologically that naturalists form them into a genus, or into one or two genera, which may then be spoken of as equally characteristic.

Sometimes a genus, or one or two genera, will range through several adjacent groups of strata, and these groups may themselves admit, either from these palæontological or from other characters, of being classed together as a larger and more general group.

In this way we have single beds, sets of beds, subgroups, and groups of beds, and these are spoken of as "formations" or "systems," according to the importance attached to their characteristics by their describer or by geologists generally.

Law of approximation to Living Forms.—If we walk through a Museum in which there is a tolerably complete collection of characteristic fossils derived from the principal groups of stratified rocks, and those fossils are arranged as assemblages in the order of super-position observed by the rocks from which they were derived, we could not fail of being struck with a general law running through them.

The fossils from the uppermost or newest rocks, such, for instance, as the shells, the crustacea, echinodermata, and corals, would seem quite familiar to us. Some of the forms would be absolutely identical with those of species now living, and even those which we could not identify with any that we knew anywhere living would still have a familiar aspect, and closely resemble some living forms. If we then went from these backwards through the different assemblages of fossils brought from lower and lower (*i.e.*, older and older) groups, the forms would become more and more strange and unfamiliar to us. This strangeness would be more striking in proportion as our knowledge of living forms was accurate and exact. An accomplished conchologist, for instance, would be much more struck with the contrast between the recent and the older extinct shells, than would one who, with the usual ignorance of "educated persons,"* knew no shells but oysters, mussels, cockles, periwinkles, and snails, and did not feel very sure about them.

The conchologist, supposing him to have never seen fossil shells before, would be at once able to declare the generic names of those coming from the newer formations, even if the species were new to him. He would say "this is a Volute or a Cone, this is a Venus or an Arca, although," he might add, "I never saw one before having that precise form and those specific characters." But as he traced the series towards the older groups, not only would he find the species of still existing genera becoming stranger and stranger, but he would find more

* The student will please to recollect that I am not here imputing blame to the "persons" but to the "education" of the present day. I have heard even of Ministers of State holding offices especially presiding over "Education," who have not hesitated in society in London to speak of scientific men as "mere beetle-hunters and bird-stuffers," as if such occupations were beneath their notice, instead of being important aids to, and worthy parts of, education.

and more forms to which he could give no generic names at all. He would have to invent new designations, and to define or describe new generic groups in which to place these older shells, so greatly would their characters diverge from any of the descriptions or definitions of recent shells.

The professor of all other branches of Natural History would find himself in precisely similar circumstances.

The conclusions to be drawn from these facts are best stated in another and more natural way.

The animals and plants living in the earlier periods of the earth's geological history, were very different from those which now exist upon the globe ; and there has been during all succeeding time a succession of fresh species, shewing a gradual approximation in form to those which now exist.

Not only did the older species perish one after the other, but most of the older genera, some families, and even a few orders have come into existence and died out, while those that succeeded them from time to time shewed forms that, with many occasional deviations, gradually grew more and more like those that now live. One or two species came at length into existence that still survive upon the earth, and these *recent* species became more and more numerous until we arrive at the existing population of the earth contemporaneous with man.

The extinction of species is still going on, man himself being now the most active exterminator. Whether new species have come into existence, since the introduction of man himself, is a problem of which a solution is, at present at least, impossible.

It appears from the above statement that the existing species of animals and plants came into being slowly and gradually; but not only was this the case with the species now living, but it must have been always the case at every period of the earth's history. The law of succession of species reigns throughout. Had any intelligent being lived in one of the later Palæozoic or earlier Secondary periods, he could still have stated his palæontological researches in the same terms we ourselves use. The now extinct assemblage of that period would then have constituted the "existing" or "recent" species, and ample evidence would have been found in the then recently deposited rocks (most of which have been long ago destroyed), of the gradually coming in of those species, and of their mingling with species then become recently extinct in rocks deposited just before the commencement of the period.

Duration of Species Proportionate to their Place in the Scale of Existence.—It is an obvious truth that the lowest forms of animal life are the most abundant, and this abundance increases in proportion to their minuteness. It will follow from this that small forms, low in the

scale, will last longer, in consequence of their surviving a greater number of hostile circumstances than will larger or higher forms.

This is in harmony with the facts that some species of Foraminifera now existing are the oldest of existing species; that the species of Mollusca are longer lived than those of Fish, and much longer than Mammalia; and that the species which range through two or three groups are rarely higher than Brachiopoda, or some class of similar rank.

Forms once Extinct never Re-appear.—It is also certain that species that have once become extinct have never been again brought into existence; and this is true also of groups of species (genera, families, orders). There is no known instance of any specific form that has once fairly died out ever making its appearance again in the deposits of any subsequent period; and this is true of many groups of allied forms. There are no Graptolites in rocks more recent than the Silurian, no Trilobites in any rocks more recent than the Palæozoic, no Ammonites in any rocks more recent than Cretaceous, and so on.

Nevertheless some genera, such as Lingula and Rhynchonella among Brachiopodous bivalves, and Nautilus among Cephalopods, have survived, *as genera*, through a long succession of species from the earliest known ages down to the present day.

CHAPTER XXV.

SUBJECT CONTINUED.

Supposed Destruction and Sudden Introduction of Assemblages of Species a Mistake.—Some geologists, trusting to the fact that small groups of beds can in some cases be found resting directly one on the other, and containing different groups of fossils, supposed that this must have been the result of the sudden and wholesale destruction of one race of animals and plants, and the wholesale introduction of new races. This supposition rested on the entirely unwarrantable assumption that these groups of beds were deposited not only consecutively in those localities, but with short absolute intervals of time between them. The reasoning formerly used (pp. 181, 182) will shew how little trust could be placed in such a conclusion, even if we were more disposed than we ought to be to rely on mere negative evidence.

Wherever we get a great formation, such as the Carboniferous formation of the British Islands, and are able to trace it over a considerable area, and study all its varieties of interstratification of groups of rock, we find the same characteristic species ranging throughout the whole vast series of rock, occurring in different parts of the formation according to the accidental circumstances of the different localities during the different portions of the period at which those parts were formed. We find the characteristic plants in the lower part of the formation in some localities, while in others they are confined to the upper parts, and conversely we get the animals that in the majority of instances are confined to the lower parts, making their appearance also in the upper parts wherever circumstances were favourable to their existence and to the preservation of their remains after death. We are, therefore, perfectly warranted, by those positive evidences in its favour, in taking as a rule the great duration, and the slow and gradual extinction of any fauna and flora. When we meet, on the other hand, with rapid changes in the fossil contents of sets of a few beds resting on each other, the legitimate conclusion is, that in that particular locality only a few beds happened to be deposited during each of the great periods that elapsed while those successive fauna and flora inhabited the earth. When the beds are carefully examined and widely traced, this conclusion is always supported, either by physical evidence

proving the discontinuity of their deposition, or else by finding other areas in which the small sets of a few beds expand into great formations.

Untrustworthiness of Negative Evidence in Palæontological Speculations.—Arguing from what we now know, it appears that the earliest life on the globe, during the Cambrian period, was that of Annelids (sea worms), and Zoophytes (either sertularian or polyzoan). It seems very difficult to suppose that these existed by themselves. Animal life now is so bound together by links, uniting species to species in such a way that, if you destroy one, you in all probability exterminate another which in some way depended on it, that it seems almost an impossibility to my mind to imagine a world inhabited by only one or two species of animals.

Waiving that consideration, however, we have in the next period certainly, a vast variety of animal life of all the sub-kingdoms, except the Vertebrata, while in the succeeding or third known period, we find remains of fishes, and then of reptiles in the fourth or fifth. Still, in all the Palæozoic series of rocks, there has yet been no trace found of a mammal or a bird. In the very lowest member of the Mesozoic series, however, namely, the Trias, though in the upper part of that member which is called the Keuper, the tooth of a mammal has occurred, and in some still newer rocks the tracks of gigantic birds and the jaws of several mammals.

Now, it may be that we have in these facts a true picture of the course of creation; that during the earlier Palæozoic periods no Vertebrata existed; that at length fishes and then reptiles were introduced, but that long ages still elapsed before birds and mammalia were placed upon the globe. On the other hand, this *may be* only the apparent, and not the real course of creation; it may appear to us so, solely from the deficiency and imperfection of our records. A single discovery of a fish scale or a fragment of a reptile in the Lower Silurian or Cambrian rocks would greatly damage the hypothesis; a tooth of a mammal in the Palæozoic rocks would upset it altogether. Negative evidence should never be taken at more than its true value, and the process requires to be indeed an exhaustive one before the non-existence of a thing can be held to be established, because we have not yet been able to find it.

The existence of Mammalia in the Secondary rocks was long combated. First one or two, and then five small under jaws were found in the Stonesfield Oolite. At first these were supposed to be marsupial only, the lowest of the Mammalia, then Professor Owen shewed that one at least, the Stereognathus ooliticus, was a placental mammal, probably one of the non-ruminant Artiodactyla, and therefore of the same division as our hippopotami and swine; another placental mammal,

Spalacotherium, one of the Insectivora, was found in the Purbeck rocks; and quite recently, by the labours of Mr. Beckles and Mr. Brodie, no less than twelve or thirteen new species of mammals have been found in the same formation. These have been determined by Dr. Falconer, Professor Owen, and Sir C. Lyell, to belong to eight or nine genera, Triconodon, Plagiaulax, etc., some marsupial, others placental. They were all found in one little bed not more than six inches thick, and within a space of twenty-two yards square, and Sir C. Lyell justly observes, that these very beds, which altogether are 160 feet thick, had been diligently explored by many observers—including the Geological Survey—during many years, one specimen only having been at length found by Mr. Brodie, and that it was not till that bed was quarried *expressly for the purpose* by Mr. Beckles that these new discoveries were made. He also remarks on the bearing of these discoveries on the value of negative evidence, as follows:—The Purbeck rocks "have been divided into three distinct groups by Forbes, each characterised by the same genera of pulmoniferous mollusca and cyprides, but these genera being represented in each group by different species; they have yielded insects of many orders, and the fruits of several plants; and lastly, they contain several 'dirt beds,' or old terrestrial surfaces and soils, at different levels, in some of which erect trunks and stumps of Cycads and Coniferæ, with their roots still attached to them, are preserved. Yet when the geologist inquires if any land animals of a higher grade than reptiles lived during any one of these three periods, the rocks are all silent, save one thin layer of a few inches in thickness; and this single page of the earth's history suddenly reveals to us, in a few weeks, the memorials of so many species of fossil mammalia, that they already outnumber those of many a sub-division of the tertiary series, and far surpass those of all the other secondary rocks put together!"

Such a thin seam, one of those small exceptions in the great series of aqueous rocks, which contains the remains of land animals, might lie hidden for centuries even in the formations which are most searched by the quarryman, miner, and geologist, or might be frequently passed through by the two former, without having been sufficiently examined by the latter. Great as have been the labours and researches of geologists hitherto, we can only look upon them as but having made a commencement, and laid the foundation for more complete discoveries being made in the future.

On the Origin of Species.—Naturalists have long experienced the utmost difficulty in determining the limits of species. This difficulty has been felt both as to plants and animals, with respect to living as well as fossil forms. One man has made several distinct species out of various forms which another has considered as mere varieties of one species. The only satisfactory test of the distinctness of species that

has ever been agreed upon is that derived from the power of a species to reproduce its like.

The individuals or pairs of a species are fertile, and produce their like, while it is impossible to procure a cross between two different species unless they are very closely allied, and then the progeny is called a mule or hybrid, and remains barren. It results from this principle that the whole of the individuals of a species are the descendants of one common parent. Doubt, however, has been cast upon this test with respect to some plants, and even to some animals. Many naturalists, for instance, believe that some of our domestic animals, as the dog, for instance, are the commingled descendants of two or three species originally distinct.

In this view, a hybrid or mule, the result of the crossing of distinct species of plants or animals, is merely an exaggeration of a mongrel or cross between distinct breeds or varieties.

Still there seems to remain an essential distinction between a species and a mere breed or variety in this respect, and not only a distinction, but a contrast, for while the offspring of distinct species are usually not only sterile but degenerate in strength and appearance, the "crossing of breeds" almost invariably improves the descendants, both in fertility and every other respect.

Mr. Darwin, who, as every one knows, has lately treated of this subject in his usual clear and admirable manner, proposes to account for the origin of species by a doctrine which he terms that of natural selection.

I will endeavour to give a brief account of his hypothesis.

Species of plants and animals have a natural tendency to produce "breeds," "races," or "varieties," under the continual influence of external modifying causes, or all those surrounding circumstances which we may include under the term of "climate." If any number of individuals be placed in a favourable "climate" (including food and everything relating to their wellbeing under the term "climate"), then those individuals will gradually become an improved breed. If the "climate" be unfavourable, the breed will degenerate.

If, again, in any region in which the same climate prevails throughout, individuals of a species of plant or animal should be produced by any physiological or other accident, differing in any important way from the other individuals of the species, and that difference (whether it might to us appear an improvement or the reverse) should be of any advantage to the individual possessing it, it would naturally be used and strengthened by use and exercise, and transmitted to the progeny of those individuals.

In this way a process would be set up naturally, similar to that which breeders of plants or animals follow designedly. A breeder

selects the individuals which happen to possess the qualities he desires, and breeds from them, taking care to surround them during the process with the kind of "climate" favourable to the success of the process.

The differences artificially produced in breeds are very striking; such as the difference between the Shetland pony, the Flemish cart-horse, and the English racer; that between different breeds of sheep and oxen; the difference between the varieties of fruits and vegetables; the different breeds of domestic poultry; the different pigeons of pigeon fanciers; and the vast variety of dogs, though Mr. Darwin believes that the latter is to some extent to be accounted for perhaps by the commingling of two or three allied species.

His hypothesis is that these varieties which are so numerous, and some of which remain so unchanged, may, if the surrounding circumstances conducive to them remain for a great length of time unaltered, result in the production of new species. He looks upon the difference between a permanent variety and a species as one which has every degree of gradation, and finally vanishes.

The obvious objection to this hypothesis is that no one has yet succeeded in producing a new species, that is, a breed or variety of animal or plant which is incapable of propagating its kind with other breeds or varieties of the species from which it was itself originally derived. This objection, however, is merely saying that Mr. Darwin's hypothesis has not yet been converted into an undoubted theory by proof tantamount to absolute demonstration.

His hypothesis may be true, even if man is incapable of doing the work of nature,* from want either of the requisite time, or of all the means which nature uses.

Mr. Darwin's hypothesis is one which the professed biologist alone is competent to discuss. To a question in pure physiology, the answer of the physiologist only is of any value as an authoritative opinion.

Mr. Darwin's hypothesis, that varieties are incipient species, or any other reasonable hypothesis, of the slow and gradual evolution of species from preceding species, would agree well with the known facts, whether palæontological, lithological, or petrological, that we meet with in investigating the structure of the earth's crust.

There are two classes of facts in the study of fossils which would be naturally explicable on such a hypothesis, and seem difficult to account for without it.

1. It is of course impossible to apply the test of sterility or fertility to the study of fossil species. The palæontological biologist is reduced to the comparison of forms only, often of parts of forms only. The diffi-

* To obviate cavil, I beg leave to state that the word "Nature" is used here as a reverential periphrasis for the Laws of the Creator.

culty of distinguishing between species and varieties presses, therefore, still more strongly on him than on the biologist, who studies living beings only. This difficulty occurs to the palæontologist when studying a number of fossils derived from the same bed of rock, and which were therefore all contemporaneous with each other.

But when the palæontologist has a great series of beds to deal with, and to trace one or more species throughout this series, he meets with another phase of the difficulty. Certain forms may be met with in the lower beds that seem to be perfectly distinct species from others in the upper beds, although allied to them, but he will in some cases meet with intermediate gradations of form in the intermediate beds, and is therefore compelled to look on those as mere varieties of one species, which he previously considered to be undoubtedly two distinct species. How is he henceforward to be sure that other forms quite as specifically distinct, and derived from different sets of beds, would not graduate into each other as insensibly if he could find the beds which were deposited in the interval between these two sets, and they happened to contain the required fossils.

If species be merely the descendants of other species, the existence of intermediate forms of gradation is a necessary and unavoidable consequence, and instead of being a difficulty, is always to be expected.

The hypothesis of descent, again, at once gives us a natural explanation of the law of approximation to living forms, and conversely, the existence of that law, which is one that cannot be gainsaid, lends a strong support to the idea of such a hypothesis, and seems imperatively to demand it. The one appears to be the natural result of the other.

This hypothesis, moreover, gives a natural explanation of the fact of the non-recurrence of species that have once become extinct.

2. There is another class of facts in palæontology which lend a strong support to Mr. Darwin's hypothesis, or at all events to the hypothesis of existing species being connected with extinct by way of descent. The geographical distribution of species at the present day seems to be the direct result of a preceding geographical distribution. The sloths and armadillos and ant-eaters now living in South America were preceded by extinct species of animals belonging to the same orders, some of which extended over parts of North as well as over South America, but none have been found beyond those limits. The extinct kangaroos and wallibis of Australia seem to have been the progenitors of the present races. The giraffe, the hippopotamus, the rhinoceroses, and the pigs of the Old Continent were preceded by species, now extinct, more or less closely allied to them, and no fossil species of those genera has yet been found in America.

On the supposition of every distinct species being an independent creation, this geographical limitation of a succession of allied species is

unintelligible, but it is the obvious result of the evolution of one species from another.

The fact that vast periods of time are necessary for such a principle to operate so as to produce the required effect, harmonises well with all the other facts of geology. The more we investigate the formation of rocks, the relations of rock-masses, the contents of mineral veins, and all other inorganic phenomena, the vaster become the periods of time which unrol themselves, fold after fold, before the strained and aching mental vision. That the past organic phenomena should require similar enormous portions of eternity for their elaboration, seems fitting to the mind of a geologist, and completes, as it were, the harmonious concord of nature's great poem.

Changes of Climate.—It is almost solely from the nature of the animals and plants that have left their remains in the rocks, that we can draw any certain conclusions as to the kind of climate possessed by different parts of the earth where those animals and plants lived. When we find in the British Islands the remains of crocodiles, turtles, large nautili, and monkeys, together with palm fruits and other tropical-like plants, we cannot resist the conclusion that the climate of the British Islands must have formerly been more like that now found within the tropics than that which they at present possess. It is true that the plants and animals are all of different species from those which now exist, and we are taught by the fact of the mammoth, or fossil elephant, and one of the fossil rhinoceroses, having been provided with woolly coats covered with long hair, and therefore fitted to live in much cooler climates than any existing species of elephant or rhinoceros, not to rely too implicitly on mere analogies of form ; still the fact of the whole assemblage of the fossils of certain great groups of rock being stamped with a tropical "facies," is very strong evidence in favour of their having enjoyed a tropical climate.

But we may extend this argument to still higher latitudes. By the zealous and enlightened labours of our arctic navigators, especially those of Sir Leopold M'Clintock, of Sir E. Belcher, and others of late, and of Parry formerly, we have been put in possession of the very remarkable fact that in latitudes where now sea and land are buried in ice and snow throughout the year, and there are several months of total darkness, there formerly flourished animals and plants very similar to those living in our own province at that time ; and it would appear that similar animals and plants were then widely spread over the whole world.

There are large tracts of country lying between 73° and 76° of N. lat., and 84° and 96° of W. long., in which the rocks contain Upper Silurian fossils. In the same latitudes, but extending farther west, beds of coal, with Carboniferous plants, like those of Europe, were

found ; and still farther north and west, extending up to 77° 20′, or thereabouts, are limestones full of Carboniferous corals and shells (Orthoceras, etc., as well as Brachiopoda), while in Prince Patrick's Island, at Wilkie Point, in lat. 76° 20′ N., and long. 117° 20′ W., Oolitic rocks containing an Ammonite (*Ammonites M'Clintocki, Haughton*) like A. concavus, and other shells, were found by M'Clintock ; and, moreover, from Exmouth and Table Islands, lat. 77° 10′, long 95°, part of an ichthyosaurus was brought by Sir E. Belcher.—(See *Fate of Franklin and his Discoveries*, by Captain Sir F. L. M'Clintock, and *Appendix* by Rev. Professor Haughton.)

These facts, all pointing in the same direction, compel us to believe that, during at least a part of the primary, secondary, and tertiary epochs, the general climate of the globe was higher and more equable than at the present day.

The existence of the plants in such high latitudes seems inconsistent not only with their present cold temperature, but also with the three or four months' darkness which must have prevailed there, so long as the axis of the earth has retained its present inclination to the plane of its orbit, or anything approaching to that inclination. If, on the other hand, we had any warrant for supposing that the earth's axis was formerly perpendicular to that plane, and that the plane of the equator, consequently, coincided with that of the ecliptic, the difficulty as regards light in the polar regions would vanish, since there would then be eternal sunshine near the poles, and alternations of day and twilight, with no real night, down nearly to the Arctic and Antarctic circles, with equal day and night over the rest of the world.

It remains for astronomers to decide upon the probability, or otherwise, of such a supposition.

It does not appear that any such shifting of the direction of the earth's axis would at all account for changes of climate in the opposite direction, of which there is nevertheless good proof, both palæontological and petrological.

It appears certain, that not only over the northern temperate regions, but as far south as the Himalayah Mountains at least, the climate was once more cold and severe than it is at present, the sea being encumbered with icebergs and the land with glaciers far beyond the limits to which glaciers and icebergs now extend.

Sir C. Lyell shewed that, so far as temperature is concerned, a great effect would be produced by shifting the position of the present lands and seas of the globe. If the land which now circles round the north polar regions, and that which we know exists near the South Pole, were sunk, the temperature of the polar regions would be raised, in consequence of the sea there not becoming so cold as land does, while, if the central portions of the great Pacific and Indian Oceans were

occupied by nearly continuous, but not very high land instead of sea, their temperature would be raised in consequence of low land under the vertical sun becoming hotter than sea does. The exact opposite effect would be produced by clustering still more land about the poles, and diminishing that which now exists in the equatorial regions of the earth.

Lyell shews that a great summer and winter of the earth's climate might be thus produced by merely shifting the place of our present continental lands.

If we supposed those lands to be broken up into islands when they were congregated in the tropics, instead of remaining as continents, so as to allow open passages for the ocean currents in all directions, and a free circulation of the warmer surface water to be set up, we might possibly have ice entirely removed from the low lands of the whole earth, and existing only on the loftiest mountain summits. (See Professor Hennessy's *Remarks on Terrestrial Climate, Atlantis, January* 1859.)

Practical importance of Fossils.—The importance of the study of fossils to all those who wish not only to learn the past history of life upon the globe, but to understand the problems involved in its present multiplicity of form and variety of diffusion, will be obvious even from the slight and hasty observations that precede. Their importance, however, is not limited to the theoretical speculations, or the philosophical conclusions that may be derived from them, for those, like many other scientific conclusions, may be coined into actual money, or money's worth, by their practical application.

If in any particular part of the earth, beds of any substance of economic value to man were formed during a particular geological period only, it is obvious that those beds, and the others in which they lie, will contain the remains of the animals and plants that lived during that period, and no others. If, therefore, the valuable beds be but a few thin seams occurring here and there in a great series, and our object be to discover where any part of that series reaches the surface, in order that we may search for the valuable beds, it is clear that the fossils will be of the greatest assistance to us.

The mere lithological character of the other beds of the series may be of little or no use to us as a guide, and may even mislead us, since there may be other series having beds of precisely similar character, but not containing the valuable beds.

The most striking instance of what is here stated generally, is the occurrence of beds of coal in the part of the series which is hence called the Carboniferous formation. Coal is not confined to that formation, since in different parts of the world good workable coal occurs in other formations; but, in Britain and Western Europe, although thin beds of coal occur in other formations, extensive beds of workable coal have only

been found in the Carboniferous formation. Coal is usually associated with black and gray shales in that formation, and the same association occurs in other formations, where the coal is too impure or in too small quantity to be valuable. Black and gray shales also occur in parts of the Carboniferous series, where there is no coal, and in other formations entirely devoid of coal. The coal miner being always accustomed to see coal associated with black and gray shale, and not having had occasion, like the geologist, to see black and gray shales in other formations, naturally looks upon the occurrence of the black and gray shale as indicative of the presence of coal. The geologist, on the other hand, having a wider experience, knows, that not only do black and gray shales occur where there is no chance of coal being found, but that even thin seams of coal occur in formations where no coal worth working has ever been found in the British area or in Western Europe.

He therefore knows, that all "indications" are worthless as evidence of the presence of the "Carboniferous formation," except the occurrence of the "carboniferous fossils."

Even where the fossils occur there may be no coal, but all sinking for coal in beds containing any other than the Carboniferous fossils is pure waste of labour and money.

Within my own experience large sums of money have been absolutely thrown away, which the slightest acquaintance with palæontology would have saved. I have known, even in the rich coal district of South Staffordshire, shafts continued down below the Coal-measures deep into the Silurian shales, with crowds of fossils brought up in every bucket, and the sinker still expecting to find coal in beds below those Silurian fossils. I have known deep and expensive shafts sunk in beds too far above the Coal-measures for their ever being reached, and similar expensive shafts sunk in black shales and slates in the lower rocks far below the Coal-measures, where a pit might be sunk to the centre of the earth without ever meeting with coal. Nor are these fruitless enterprises a thing of the past. They are still going on in spite of the silent warnings of the fossils in the rocks around, and in spite of the loudly-expressed warnings of the geologists, who understand them, but who are supposed still to be vain theorists, and not to know so much as "the practical man."*

* I have elsewhere stated my belief that the amount of money fruitlessly expended in a ridiculous search after coal, even within my own experience, would have paid the entire cost of the Government Geological Survey of the United Kingdom. It is a curious perversity of the human mind, that men prefer to take the advice of those whose interest it is to get them to spend money, rather than the warnings of those who can have no interest in inducing them not to spend it.

PART III.

HISTORY OF THE FORMATION OF THE CRUST OF THE EARTH.

CHAPTER XXVI.

PRELIMINARY OBSERVATIONS.

In the two preceding parts we have been dealing with general principles :—

In the first place, we examined the composition and mode of production of rock generally ; in the second, the great structures which are common to rocks of all kinds and of all ages ; while, in the third, we considered fossil animals and plants in their relations to living beings, and mentioned some of the general facts of distribution observed by them, and general conclusions to be drawn from them.

We had frequent occasion to note the vast periods of time required for the production of the different phenomena we met with, but we did not stop to consider the relations of these several periods of time to each other, or to describe in regular order and sequence the events which had happened. This is now what remains for us to do.

We have to give a history of the formation of the crust of the earth, by tracing out the order of succession of the different rock groups of which it is made up, noting the causes which operated in their production, and gleaning, from their relation to each other, some notion, perhaps, of what happened in the periods that intervened between the times of their production.

The way in which this knowledge is to be gained, will, I think, be sufficiently obvious from what has been said before. At page 234, *et seq.*, we saw, that after having acquired a knowledge of the number and nature of a series of beds, by examining a cliff on the sea-shore, or other " section" where they were well exhibited, any little natural or

artificial excavation in the interior of the country which enabled us to identify one of these beds assured us of the presence of the rest above and below it. By searching out places where such "sections" are to be seen, and then following them by different indications across countries, and identifying them either by lithological or palæontological characters, or by actually following their outcrop without losing sight of them, and performing the same process for the sets of beds that successively cover them, or rise up from beneath them, we eventually survey great tracts of country, and arrive at a knowledge of the order and succession of subterranean groups of rock, to a much greater depth than it would be possible to reach to by any process of mining or direct excavation.

The history of the formation of the whole crust of the globe, then, is to be learned by piecing together our knowledge of different parts of it, each part being separately investigated, and joined to another by means of some portion or portions that are proved to be common to the two. Suppose, for instance, that the group of beds from *a* to *b* (fig. 28, p. 234), were seen in one place, and that we there learnt the history of their production, and gained thereby a record of which the earliest portion is contained in the beds at *a*, and the latest in the beds at *b*; and suppose that no beds above *b* were there visible, but that we could either trace *b* into another district, or could identify it there, and that we then found another great series of beds over *b*, and there learnt the history of their production, carrying it on to the beds about *d* for instance; it is clear that we should there extend our record from *a* to *d*, and this we should do, whether or no there may be any one place where the whole series of beds, from *a* to *d*, be simultaneously present.

We might give this history in either of two ways, namely, by investigating or *tracing* it backwards from the present to the past, or by *narrating* it as nearly as possible in the order in which it occurred. I prefer the last method as the shorter and more intelligible, since it is hoped that the previous parts of this work will have sufficiently prepared the student to understand it.

As, however, to narrate this history in full, even so far as it is already known, would require a library rather than a book, what will be here given must be taken as a mere abstract, a chronological table rather than a history, by means of which the student will be able to refer to its proper period any more detailed account of its different portions, which he may either read of or observe for himself.

Even this abstract is a very imperfect, broken, and fragmentary one. Comparatively few parts of the earth's surface have as yet had their structure even sketched out; still fewer have been accurately surveyed, and had their details thoroughly unravelled. Many of the events, therefore, which are now supposed to have occurred contemporaneously

in different places, may in reality have occurred in succession ; many which are supposed to have directly succeeded each other may have been separated in reality by great spaces of time, of which there are no records as yet discovered, or of which none may ever be found. It is obvious that all future discoveries may add to the time we know to have elapsed, but cannot diminish it.

As the structure of the British Islands is better known than that of any other part of the globe of equal dimensions, and contains a more complete series of rocks in a small space than any other district, we shall take that as the principal authority for our history, pointing out the several groups of rock which were produced in this part of the globe during the several periods, mentioning a few of the principal fossils they enclose, and then give some of those other well-known typical groups of rock which are believed, or are known, to have been deposited contemporaneously with them in other parts of the earth. Where a group of rocks is known of which we have no cotemporary representative in the British Islands, it will of course be best to describe it from its best known locality. Our history, however, will be chiefly that of the formation of the Celtic or British province, as we may call it, with occasional reference to the history of other provinces.

Chronological Nomenclature.—One difficulty meets us at the outside as to our nomenclature, that is, as to the names we are to give to the different periods of past time. This difficulty must at present be evaded, since the time has not yet arrived, that is to say, our knowledge is not yet complete enough to enable us to overcome it.

The early geological observers described certain kinds of rock, to which particular names were given. These names were, in the first instance, lithological, or descriptive of the kind of stone, of which Chalk and Oolite are instances. In other cases they were petrological, such as Mountain Limestone, Coal-measures, etc. Others again were geographical, of which Wealden, Neocomian, Silurian, Oxford Clay, are examples ; while others were local terms adopted by geologists, such as Lias, Cornbrash, Gault, etc. Such terms as Old and New Red Sandstone were combined lithological and petrological terms, referring at once to the kind of rock of which they were composed, and their relative place in the series.

Gradually, as extended observation shewed that aqueous rocks occurred in a certain order, and formed a succession of beds regularly superimposed one upon the other, a chronological sense began to be extended to these terms, for it was clear that each bed, and each group of beds, was newer than those below it, and older than those above it, while those occupying the same place in the series were contemporaneous. Thus, *The Oolite*, and *The Chalk*, came to mean, not only the rocks to which those names were first and truly applied, because they

consisted of the kind of stone called Oolite and Chalk, but also all other kinds of rocks which, having been formed about the same period as these, occupied the same relative place in the general series, and contained the same fossils. The Cretaceous or Chalk rocks, then, might be made either of white chalk, of black marble, of brown sandstone, or blue slate ; " Cretaceous rocks" meaning in reality only rocks of *the same age* as the Chalk. Silurian rocks, in like manner, mean those *of the same age* as the rocks of Siluria, and so of the rest. This double signification of words is almost unavoidable, and the student will find himself naturally and inevitably falling into it in the course of his geological pursuits. When, then, we speak of Silurian, or Carboniferous, or Oolitic, or Cretaceous *periods* of time, the reader must pardon the apparent contradiction in the terms, and look on the names as *names only*, and not as descriptive designations.

This is indeed what we do in ordinary language, and in human history, since we speak of the Babylonian, the Greek, or the Roman periods, and thus give chronological significations to mere geographical terms.

It is doubtless puzzling enough at first, if we are shewn in South America a mountain of blue clay-slate, and told that that is " Chalk ;" or, if we find the same term applied, in North America, to a group of sandstones, shales, and coals. Many persons are, in like manner, perplexed when they find, in the British Islands, clayslate and gray limestone spoken of as " Old Red Sandstone ;" but this difficulty vanishes if we recollect, that when used geologically these words mean a period of time, and not any particular kind of rock.

The term Old Red Sandstone did originally mean a kind of rock, or rather, it was at first applied to a large group of rocks, of which red sandstones were the most conspicuous portions, although beds of clay, and even thin beds of limestone, as well as beds of white, yellow, or green sandstones, did occur in the group. It was called *old*, because it lay below the Carboniferous rocks, while there was another group of similar red sandstones (with other subordinate beds) which lay above the Carboniferous rocks, and was, therefore, called *new*. The " Old Red Sandstone " then was the name applied in Scotland, and in the borders of England and Wales, to a great group of rocks lying below the Carboniferous group, and above the group which was afterwards called Silurian. But it has been already remarked, that formations, when they are traced laterally over large areas, are often apt to change their lithological characters, in consequence of the gradual termination of one set of beds and the setting in of beds of a different kind. When then we trace the Old Red Sandstone laterally across a large tract of ground as we can trace it across the south of Ireland, for instance, we need not feel surprised at its gradually passing from a sandstone formation into a clayslate formation. As it is possible in Ireland to walk along it from one

district to the other without ever leaving it, it is clear that if it ought to be called Old Red Sandstone in the one district, it would be giving two names to one group of rocks, if we gave it another name in the other district.

Whether the name "Old Red Sandstone" be a good one, is another question. It is retained simply because it is generally understood, that by that designation we mean the rocks lying next below the Carboniferous group. It is avowedly a "provisional" designation, just exactly as all the names of the great groups of stratified rocks are provisional. They are temporary names adopted for present purposes, and have *grown into use*, and will continue to be used until they are superseded by more appropriate terms, which increasing knowledge only can shew to be more appropriate. Many attempts have been made to introduce a more systematic nomenclature; but they have all failed, because the attempt required almost prophetic powers on the part of the inventor, who should know what would be wanted in a few years time, as well as what is wanted now.

Any scheme of nomenclature which is not expansible in all directions, and does not admit of readjustment and interpolation, according to circumstances in all its parts, will in a short time be found the fetters rather than the clothes of the science.

In the maps and publications of the Geological Survey, for instance, the letter "a" was adopted for the rocks of the Cambrian period, as being the earliest period of which anything was known; recent discoveries of Sir R. I. Murchison and Sir W. Logan, have, however, shewn us rocks belonging to still earlier periods, and if we wish to letter them on our maps, we find ourselves at a loss for a letter before "a" in the alphabet.

In speaking of the great groups of stratified rocks or "formations," therefore, the student must clearly understand, that their names are often used also as the names of the periods of time in which they were formed, and accustom himself to detach from these names all other meanings they may have.

The igneous rocks, however, are named on lithological grounds only. The crystalline aggregate of feldspar, mica, and quartz, is called granite, no matter where it was formed, or with what stratified rocks it may be associated. Felstone, greenstone, trachyte, and basalt, and all the other names of igneous rocks, refer in like manner, solely to their mineral constituents and texture, at whatever period they were consolidated, or in whatever part of the earth's crust they are found.

All names, moreover, which have a special lithological signification, such as shale, grit, dolomite or magnesian limestone, oolite, etc., are applied to the variety of rock quite independently of any reference to the time it was produced, or the formation to which it belongs.

Any limestone of any formation may become magnesian; any lime-

stone of any formation may become oolitic. It is only when that accidental character has, by use, been applied to some particular group of stratified rocks, which are then spoken of as *The* magnesian limestone, or *The* oolite, that the words acquire a technical chronological signification, that is to say, may be used to designate all those stratified rocks which were contemporaneous with the group to which the name was first applied.

I must, therefore, request the student now to fix his attention chiefly upon *time*, and to suppose that all geological time is divided into three great portions or epochs, which we may call Primary, Secondary, Tertiary.

The Primary epoch means simply that which preceded the Secondary, the first portion of time that we know anything of, not by any means the first time of all, since as to that we know nothing. The Primary epoch has no definite starting-point. Future investigations may shew us formations lying below those, which are the lowest we have hitherto discovered, so that our chronological commencement is lost in the remote past. The geological history can only begin like a fairy tale—"once upon a time there was a sea, and in that sea certain rocks were formed," and so on.

The Secondary epoch, in like manner, means that which succeeds the Primary. Geologists agree to draw a line somewhere in the series, and to take that line as the boundary between the Primary and Secondary epochs.

So with the Tertiary epoch, a certain boundary line is drawn as the close of the Secondary epoch, and all time since then is included in the Tertiary epoch.

As synonyms of these words, Primary, Secondary, and Tertiary, the words Palæozoic, Mesozoic, and Kainozoic, signifying the periods of ancient, middle, and modern life, have been proposed by Professor Phillips, and pretty generally adopted. Geological time, then, may be thus arranged :—

3. Tertiary or Kainozoic Epoch.*

n. Human, Historical, or Recent period.
m. Pleistocene period.
l. Pleiocene period.
k. Meiocene period.
j. Eocene period.

* The mode of arrangement adopted in this table is intended to indicate that our chronology depends on the fact of super-position of rock groups, and that it therefore commences with the lowest of these groups.

2. Secondary or Mesozoic Epoch.

   i. Cretaceous period.
   h. Oolitic period.
   g. Triassic period.

1. Primary or Palæozoic Epoch.

   f. Permian period.
   e. Carboniferous period.
   d. Devonian period.
   c. Upper (or True) Silurian period.
   b. Lower (or Cambro-) Silurian period.
   a. Cambrian period.
   Præ-Cambrian periods.

Edward Forbes, in one of his presidential addresses to the Geological Society of London, suggested that both from palæontological and petrological considerations, it might be better if we obliterated the division between the Secondary and Tertiary epochs, and divided geological time into two epochs only, namely, Palæozoic and Neozoic. Perhaps, as our knowledge becomes more complete, this suggestion may be carried out. The most marked characteristic of the Tertiary epoch is, that the rocks deposited in it contain the remains of species that still exist. These in the earlier Tertiary deposits are very few, and if those few were now to die out and become extinct, the characteristic would be lost, and the palæontological distinction between Secondary and Tertiary deposits become more arbitrary than it is.

Note.—The student, in reading the older geological works, will meet with other terms than those mentioned above, which it will be as well to explain. An opinion once existed that all such rocks as granite, together with the crystalline schists, such as gneiss and mica schist, were *primitive rocks*, and that the ordinary stratified sandstones, clays, and limestones, were derived from these supposed primitive rocks; they were therefore called secondary, in the sense of derivative, rocks. Extended observation, however, shewed a class of rocks with characters apparently intermediate between those which were supposed to belong to these so-called primitive and secondary rocks. For this class the term "transition" was invented. About the same time, the idea of the *primitiveness* of the granites and crystalline schists began to be shaken, and the term primitive was modified into primary. There were also other rocks discovered lying above those which had hitherto been taken as the uppermost of the secondary, and to these the term tertiary was naturally applied. But when granite was found to be not only not a primitive but an intrusive rock, and also not solely intrusive into primary rocks, but intrusive into rocks of almost all ages; and when Sir Charles Lyell shewed that the crystalline schists were in reality metamorphic rocks, and that their crystalline schistose character was not peculiar to any geological period, the term "transition" was gradually disused, and the word primary lost the lithological taint which it had derived from its primitive original, and acquired its present purely chronological sense, as simply meaning all rocks older than the secondary. There was a barbarous word once in use, as a kind of synonym of the term "transition," this was "grauwacke," a word now altogether discarded even in a lithological sense. It was one of those words that meant anything or nothing, and served merely to conceal our ignorance of the true history of the rocks to which it was applied.

PRIMARY OR PALÆOZOIC EPOCH.

Præ-Cambrian Periods.

In geological history, as in the history of most human empires, it is difficult to point out any definite commencement. If we assume a starting point, we must, of course, allow for great periods of preceding unreckoned time, and for many unrecorded events which led up to those which we are about to describe. The progress of geological investigation has lately disclosed to us some records of a date earlier than had been previously recognised. Sir Roderick Murchison in Scotland, and Sir W. Logan in Canada, with their several colleagues and fellow-labourers, have shewn distinctly what was only surmised previously, that certain great masses of highly metamorphosed rocks come out from underneath other masses, which belong either to the Cambrian period, or to an older one.

Scotland.—Sir R. I. Murchison has lately surveyed the north-western extremity of Scotland and the surrounding region, and has published his results in several papers, accompanied by a sketch map, in the journal of the Geological Society, London, and subsequently in a separate map by himself and Mr. Geikie, with explanatory notes.

Their results have been corroborated by the examination of the country by Professors Ramsay and Harkness, and other competent observers.

They are briefly as follows :—

In the Hebrides, and at different parts along the western shore of Sutherlandshire, great masses of highly crystalline gneiss are visible, often consisting of alternate hornblendic and quartzose folia, but having sometimes feldspathic and micaceous layers, with occasional beds of limestone and ironstone. The foliation coincides with the stratification, and the strike of the rocks is N.W. and S.E. (or at right angles to the general strike of other parts of the country), the beds dipping either N.E. or S.W., more frequently the latter. They are here and there traversed by veins of granite proceeding from larger intrusive granitic masses, and also by dykes of greenstone. Upon the highly inclined and greatly denuded edges of these beds, rest, quite uncomformably, thick beds of a red sandstone and conglomerate, which is itself covered unconformably by beds which are proved to be Cambro-Silurian by the fossils they contain. (See diagrammatic section, fig. 106.)

This red sandstone and conglomerate then must be either Cambrian or some still older deposit, and the gneiss formation below it must certainly be of præ-Cambrian age. Sir R. Murchison at first described it as Fundamental gneiss, a term which could only be accepted as applicable to Scotland, since still lower rocks may hereafter be seen in other dis-

tricts. In the last paper, therefore, by himself and Mr. Geikie, he considers it as contemporaneous with Sir W. Logan's Laurentian gneiss, and speaks of it by that designation.

It seems to me, however, that while it is most probable that they are of contemporaneous formation, it would be better, in absence of any positive proof of that fact, to avoid the assertion of it, and to retain the term Lewisian gneiss once suggested by Sir Roderick, or else to call it the Hebridean gneiss, or to use some other designation which shall be clear of all chance of error.

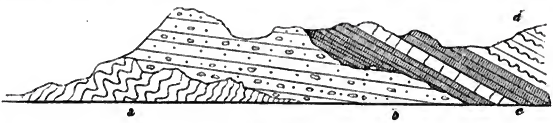


Fig. 106.

Diagrammatic section, shewing the Præ-Cambrian rocks of the northern Highlands. From Sir R. I. Murchison's papers in Geological Journal, vols. xv. and xvii.

d. Crystalline, gneissose, and micaceous flags.

c. Quartz Rock and Limestone, with Orthoceras, Piloceras, Maclurea, Ophileta, Murchisonia, and Orthis striatula in the Limestones, and annelid tubes in the Quartz Rock.

b. Red Sandstone and Conglomerate, 2500 feet thick, formerly supposed to be Old Red, now seen to be Præ-Cambro-Silurian, and therefore probably Cambrian.

a. Gray hornblendic gneiss, with granite veins, etc.

Ireland.—It is probable that some of the highly metamorphosed rocks of the north of Ireland may consist of this Præ-Cambrian gneiss.

Canada. Laurentian series.—Sir W. Logan and his colleague Mr. Murray, have described in North America an immense extent of gneiss, forming the whole country north of the St. Lawrence. This is sometimes hornblendic, sometimes micaceous, gneiss, and often alternates with, or passes into beds of mica schist. It also contains one or two large irregular beds of crystalline limestone, and bed-like masses of magnetic oxide of iron and other minerals. Veins and intrusive masses of granite, syenite, and greenstone, frequently traverse these rocks.

The beds are highly inclined and greatly contorted, so as to render all calculations as to thickness impossible, beyond the general conclusion that it is very great.

Sir W. Logan has no doubt of their having been originally an ordinary sedimentary series, and their having assumed their present crystalline character from metamorphic action. He has given the name of the "Laurentian series" to them.

In the neighbourhood of Lake Huron, this Laurentian series is covered unconformably by rocks which lie below the base of the Cam-

bro-Silurian series of America ; that is to say, by rocks which are either of the same age as the Cambrian, or still older.

The Laurentian series, therefore, like the Hebridean gneiss of Scotland, is of Præ-Cambrian age.—(*Report of the progress of the Geological Survey of Canada.*)

Scandinavia.—It is probable that the highly metamorphosed rocks, which form the mountains of Norway, belong wholly or in part to the Præ-Cambrian periods.

Other parts of the World.—Future research will probably extend this assertion to the gneiss and mica schist found in other parts of the world, perhaps to some of that of South America, for instance, or Australia, or parts of Africa and Asia, where such rocks are now known to exist, or may hereafter be discovered.

It has been already observed, that we can never hope to discover the unaltered deposits of the earlier ages of the earth's history. The aqueous rocks of the *earliest* ages have doubtless long ago perished utterly, either from erosion by water or from having been re-absorbed into the molten interior of the earth.

The oldest sedimentary rocks now left anywhere upon the globe, must necessarily have suffered more from these two actions than any newer rocks. The formations we are now treating of are some of these, but their records are nearly obliterated, and their history, therefore, brief and obscure.

No traces of organic remains have yet been recorded as observable in any Præ-Cambrian deposit, though the presence of limestones in the gneiss, both of America and Scotland, would seem to require the existence of animal life for its production.

CAMBRIAN PERIOD.

Lower Cambrian of Professor Sedgwick.

The lowest rocks visible in North Wales and its borders having been called *the Cambrian* rocks, the period in which they were deposited may be called provisionally the Cambrian period.

Typical Rocks.

North Wales.—These rocks may be seen largely developed in the hilly ground between Harlech and Dolgelli, in parts of Caernarvonshire west of the Snowdon crest, and in Anglesea, where, however, they are much metamorphosed into chloritic schists and quartz rocks. They are still more largely exposed in the Longmynd, a range of hilly ground to the north-west of Church Stretton in Shropshire.

In sheet 36 of the Horizontal Sections of the Geological Survey of Great Britain, the following beds are described by Mr. W. T. Aveline, the thicknesses being of course approximate, but on the whole nearly correct :—

	Feet.
Coarse red sandstone	7000
Red sandy micaceous shale	300
Hard course red sandstone and shale . .	4500
Hard gritty gray sandstone . . .	1500
Purple sandy shale	100
Reddish brown coarse sandstone . . .	2000
Purple shale and sandstone	4000
Gray rock, very hard	1000
Hard conglomerate	200
Hard sandstone	400
Grayish blue slaty shale	2000
No base seen	23,000

Section, fig. 107, is a reduction of that in sheet 36 (*Hor. Secs. G. S.*), and will serve to give an idea of the way in which these rocks lie, and how they are covered by others.

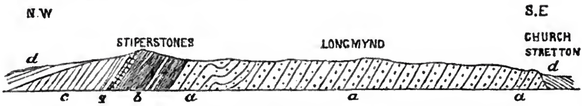


Fig. 107.

Section across the Longmynd, reduced from sheet 36 of the sections of the G. S. Length of section about nine miles.

d. Upper Silurian (Wenlock shale, and Llandovery sandstone).
c. Llandeilo flags. } Lower Silurian.
b. Lingula flags. }
a. Cambrian grits and slates.

The section in sheet 34, likewise drawn by Mr. Aveline, is generally similar, but exhibits an apparent thickness of 28,000 feet. That in sheet 37, drawn by Mr. Selwyn, across the country between Harlech and Dolgelli, shews 8000 feet of thick beds of hard gray, and greenish gray quartz rock, sandstone, and blue, green, and purple clay slate, the lower part of the series not being seen.

The section on sheet 31 of the Hor. Sec. of the Geological Survey was drawn by Professor Ramsay, and crosses from the Menai Strait over Glyder Fawr to the north of Snowdon. It shews the upper 5000 feet of the Cambrian series, consisting of green and purple slates, grits,

sandstones, and conglomerates, the pebbles in the latter consisting of quartz, quartz rock, purple sandstone, blue slate, black slate, quartziferous porphyry, and green jasper.

The Penrhyn and Llanberis slate quarries are worked in a band of slate, in the upper part of this series.

Characteristic Fossils.—No traces of organic remains have as yet been observed in these rocks in North Wales. In the Longmynd, however, Mr. Salter discovered on the surface of some of the slabs numerous small pits occurring in pairs, which he believed to be the burrows of small sea-worms, and called *Arenicolites Didyma*, and also an obscure impression, which he supposed to be that of part of a trilobite, which he called *Palæopyge Ramsayi.* This, however, always appeared to me to be nothing more than an accidental marking on the surface of a piece of rock.

Ireland.—In the northern part of the County Wicklow; in the hill of Howth, in County Dublin; and in the Forth mountain district of South Wexford, are great masses of rock, believed to belong to the same series as those just described in North Wales. Like them, they consist of massive beds of grit and slate, of dull green, brown, purple, and liver coloured hues, but in Ireland they have also many thick, but irregular, and often interrupted, beds of brown and yellowish quartz rock interstratified with them.

They are greatly disturbed and confused, so that no continuous section can be followed in them, although single detached exposures shew thicknesses of several thousand feet.

Bray Head, the Devil's Glen, and the hill called Carrick MacReily south of that glen, the cliffs and rocks of Howth, exhibit characteristic examples of the rocks, while those of Wexford may be seen on the banks of the Slaney, and on the coast about Cahore Point.

Fig. 108 is a section representing the structure of Bray Head.

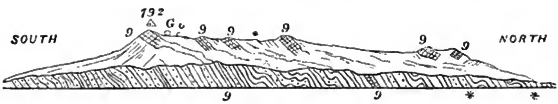


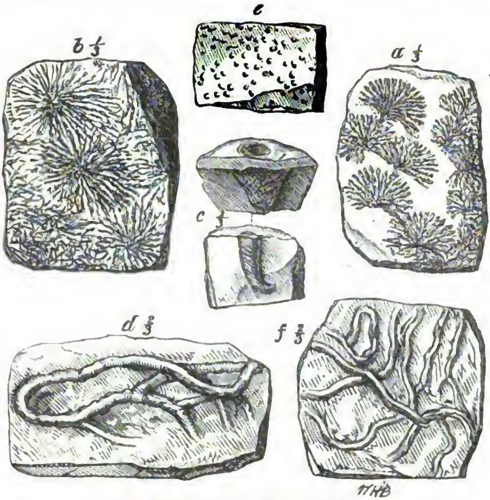
Fig. 108.

Sketch section of Bray Head. Length of section about 2 miles.
9. Quartz rock. *G b.* Granite blocks.

Note.—In this figure the lower part is intended to represent the coast section, and the upper part the slope of the hill above it. There are more bands of quartz rock on the hill top than appear in the sea-cliffs, but the one which forms the summit, 792 feet, comes down to the cliffs, as indicated by the two lines; the beds in the cliff were cross-barred in the original drawing, although that character has been omitted in the wood-cut.

Characteristic Fossils.—The late James Flanagan, fossil collector to the Irish branch of the Geological Survey, detected the little radiated

zoophyte which Edward Forbes named Oldhamia, after Professor Oldham, who was then the local Director of the Survey. Dr. J. Kinahan found marks on the rocks of Bray Head like the mounds and holes of lob-worms, and was led thereby to the discovery of the casts of the



Fossil group No. 1.*—Cambrian fossils.

a. Oldhamia antiqua.
b. ———— radiata.
c. Histioderma Hibernicum.
d. Annelid? tracks.
e. Arenicolites didyma.
f. Molluscan? tracks?

tubes below, and by a lucky blow disclosed one which retained beautifully distinct marks of the tentacles, to which scanty justice is done in the figure, *c.* He named the species *Histioderma Hibernicum.*

Note.—These specimens may be seen in the Palæontological Gallery of the Museum in Stephen's Green, Dublin, which was originally founded as the Museum of Economic Geology in Dublin, avowedly on the model of the one then established in Craig's Court in London, and now removed to Jermyn Street. The title of the Museum in Dublin has since been altered into the "Museum of Irish Industry," but the geological part of it consists of the collections of fossils, rocks, and minerals made by the Geological Survey in Great Britain and Ireland, together with subsequent purchases made by the Director, Sir R. Kane.

* The fractional numbers appended to these figures denote the proportions they bear to the originals, as $\frac{1}{3}$, one-third, etc. If the highest figure be the numerator, as $\frac{3}{1}$, it would mean that the figure was three times the size of the original.

The fossil group No. 1 contains representations not only of the characteristic, but of all the known fossils of the Cambrian rocks, except the imaginary Palæopyge. The Oldhamia radiata is very common in certain beds of purplish and greenish arenaceous slates in two or three places on Bray Head. O. antiqua is more rare, but has been found not only at Bray Head, but at Howth, and Greystones by Dr. Kinahan, and was procured largely from Carrick mountain, by J. Flanagan, in soft greenish slate.

The Histioderma has not yet been found anywhere except at Bray Head, where it was discovered by Dr. Kinahan. It was figured and described by him in the Journal Geol. Soc., Dub., vol. viii., p. 68.

Bohemia.—Probably Stage A (crystalline schist) and Stage B (slate and conglomerate) of M. Barrande. No fossils known.

Scandinavia.—Regio 1, Fucoidarum of M. Angelin is also most probably of this period.

America.—The Huronian Series.—Mr. Murray, in his report to Sir W. Logan for the year 1856, describes a great series of green slates, often conglomeritic, and with one inlying band of limestone, the series having a total thickness of not less than 10,000 feet, as lying above the Laurentian series, and passing "unconformably below the lowest of the fossiliferous strata of the Silurian system."

We may then assume that this Huronian series was deposited during the Cambrian period, although no fossils have as yet been found in it.

The *Taconic System* of Dr. Emmonds is possibly of the Cambrian period, so far as its lower portion is concerned, though its upper part is clearly Cambro-Silurian.

Life of the Period.

Although Edward Forbes named the two species of Oldhamia, he did not discuss their zoological relations beyond pointing out their resemblance in some respects to a Sertularian, and in others to a Bryozoan (Polyzoan) animal.—(*Journal Geol. Soc., Dub.*, vol. iv., p. 20.) Dr. Kinahan describes the genus at length (in the Trans. R. I. Academy, vol. xxiii., science), and believes them to have been zoophytes, allied to Sertularia, though other highly competent judges think they were more probably Polyzoan.

There can be little doubt of the tubes under the mounds with central holes, called Histioderma by Dr Kinahan, being the burrows of sea-worms.

These fossils are more than ordinarily interesting, as being the first distinct traces of life upon the globe that we as yet know anything of. Are we warranted in looking on them as being the earliest forms of

life that existed on the globe? It seems to me that this would be an unwarrantable conclusion.

The existence of beds of limestone in the Præ-Cambrian rocks of North America, seems to involve the supposition of the existence of organic beings, in order to secrete the carbonate of lime from the waters of those early seas. Whether that be necessary or not, the intense metamorphism which has affected all the Præ-Cambrian rocks we yet know, may well have obliterated all traces of their organic remains.

The argument that no fossils, except the few above mentioned, have yet been found in so vast a thickness of Cambrian rocks as is shewn in Wales and Ireland, or the Huronian and lower Taconic series of America,—and that if more had existed their remains must have been discovered, is certainly one well worthy of consideration. Nevertheless, it is not entirely conclusive against the existence of other organic beings, either during the Cambrian period or before it. We have in South Wales and South Ireland as vast a thickness of red and green sandstones and clays, of much more recent date, in which fossils are equally rare over very large areas. The Old Red Sandstone (so called) of Kerry and Cork exhibits detached sections in the heart of the formation, apparently 10,000 or 12,000 feet thick, in which no search has yet detected the trace of a fossil. Where affected by slaty cleavage, the rocks are often so precisely similar to the Cambrian rocks of Wicklow, that an observer unconsciously transported from one district to the other, would be quite unaware that he had changed his "formation." Yet underneath the Old Red Sandstone of South Ireland and South Wales lie several large fossiliferous groups of rock. Had those fossiliferous groups been so metamorphosed as to have had their fossils obliterated, and the Old Red Sandstone of the British Islands been more indurated and generally "cleaved," and here and there metamorphosed into mica schist and gneiss, we should have regarded the few plants or other fossils it occasionally contains in its uppermost beds as the earliest traces of life, and the Carboniferous fossils might have been considered its first great assemblage, as the Cambrian and Cambro-Silurian fossils are often now considered.

If we look at these traces of life and attempt to draw a reason from them, *à priori*, why they should be the first living forms that existed on the globe we can find none. It seems, as before pointed out, impossible that animal life could commence its existence before vegetable life was abundant, on which it could be supported. The earliest life of the globe then must have been vegetable. Even, however, if we grant that, and suppose that that early vegetable life perished without leaving any trace of its existence, what reason can we see why an annelid and a zoophyte or zoophytic-mollusc, so widely separated as they are in the scale of existence, should be the first of all created beings?

Can we conceive the world peopled by Oldhamia and Arenicolites, and Histioderma alone? Such a notion seems to me an absurdity. Their analogues of the present day serve as links in the chain of animal life, not only in the eyes of the biologist who studies their physiological relations, but also, doubtless, as subservient to the well-being of other animals whose very existence depended upon them. To me, I must confess, the existence of such detached portions of that chain is as good evidence of the existence of intermediate links between them, and of others indefinitely beyond them on each side, as would be the finding of two broken links of a watch chain evidence that the remainder of the chain had existed along with them.

It is of course impossible to tell the extent of the chain in either direction, but intermediate links must have been there; and there is no great probability of Oldhamia having been the lowest, or Histioderma the very highest of the living beings of the Cambrian period.

CHAPTER XXVII.

LOWER (OR CAMBRO-) SILURIAN PERIOD.

UPPER CAMBRIAN OF PROFESSOR SEDGWICK.

THE term Silurian is derived from the name of an old British tribe, the Silures, who inhabited part of South Wales; their borders being, for geological purposes, a little extended into Shropshire, on the one hand, and Pembroke on the other, and the district christened Siluria. The rocks, first surveyed in that district by Sir R. I. Murchison, were divided by him into two series, an upper and a lower. These rocks, especially the lower part of the series, were afterwards found by the Geological Survey to spread to the north-west in many large undulations so as to extend throughout North Wales also, where they were first surveyed by the Rev. Professor Sedgwick. They may conveniently be separated into two series, the Lower (or Cambro-) Silurian, and the Upper Silurian or Silurian Proper; and, as before, we may take these terms for the provisional designations of the periods during which they were formed.

TYPICAL ROCKS.

Wales.—Merionethshire and Caernarvonshire in North Wales, and Caermarthenshire in South Wales, afford us the best developed and most typical groups of the rocks formed during this period.

The groups are the following:—

	Feet.
4. Lower Llandovery rocks	1000
3. Bala beds, or Caradoc rocks	6000
2. Llandeilo flags	5000
1. Lingula flags	5000

The diagrammatic section given in Fig. 109, will shew the relations of these groups to each other in the county of Merioneth.

This section is condensed (by omitting the igneous rocks, and the curves and fractures which cause the same beds to be repeated over the ground) from that on sheet 37 of the Horizontal Sections of the Geolo-

gical Survey, which runs, from near Harlech, across the country south of Bala Lake. It was run by Mr. Selwyn, Mr. Aveline, and myself.

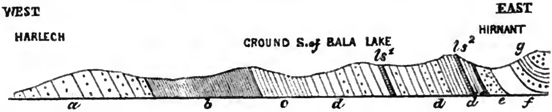


Fig. 109.

			Feet.
Base of Upper Siln.	g.	Denbighshire sandstone (Wenlock fossils)	9500
	f.	Tarannon shales (pale slate)	500
Lower, or Cambro-Silurian.	e.	Lower Llandovery sandstone	200
	d.	Bala beds; ls.2 Hirnant limestone in Bala beds; ls.1 Bala limestone in Ditto	5700
	c.	Llandeilo flags	3300
	b.	Lingula flags	5000
	a.	Cambrian rocks	8000

The relation of the lower part of the Cambro-Silurian series to the Cambrian rocks is also shewn in Fig. 107, where, however, the upper part of the Cambro-Silurian series is concealed by unconformable beds belonging to the Upper Silurian series.

Sheet 31 of the Sections of the Geological Survey, drawn by Professor Ramsay from the Menai Straits over Glyder Fawr, shews a similar relation and succession of groups.

In all cases in North Wales, there seems to be a perfect conformity between the Cambrian and the base of the Cambro-Silurian series, and a regular gradation, so that it is difficult to fix upon any determinate boundary between the two. This is the case even with the sub-divisions of the Cambro-Silurian rocks themselves, since the dark slates and grits or flags, of the Lingula flags, Llandeilo flags, and Bala beds, are often so similar, and graduate one into another so gently, that no good physical boundaries can be detected between the groups, and we are dependent solely on the fossils for their separation.

In South Wales the obscurity is greater on account of the lie of the rocks, which are greatly disturbed, often vertical, and traversed by numerous and rapid flexures, so that although the type of the Llandeilo flags is to be sought in Caermarthenshire, it would have been impossible there to determine the whole series. It was necessary, indeed, to trace the rocks, step by step, from Caermarthenshire into Merioneth and Caernarvon before this could be properly done, as it is also necessary to follow them from both North and South Wales into Shropshire, before their relations to the deposits of the next period can be completely understood.

Lingula Flags.—Immediately to the westward of the Cambrian rocks of the Longmynd in Shropshire, and therefore above them, since the dip of the rocks there is to the west, come some dark slaty shales with beds of grit and flagstone, having a thickness of 3000 or 4000 feet (see fig. 107).

In Merionethshire, in the Barmouth and Harlech country, the Cambrian rocks, rising up *en masse* about Rhinog Fawr, stretch round it with a semicircular sweep, dipping near Harlech to north-west, near Trawsfynnydd to north, and then curve round so as to dip eastward, thence down to Barmouth. They everywhere dip under, and are succeeded by, masses of dark slate, often ferruginous, with banded arenaceous flags, the surfaces of which are spotted with impressions of lingulæ. The beds thus characterized have a thickness of about 5000 feet in this locality.

In like manner, in Caernarvonshire, between the Menai Straits and the crest of the Snowdon range, the Cambrian rocks dip beneath 3000 or 4000 of dark blue or black slate, with gray and brown sandstone.

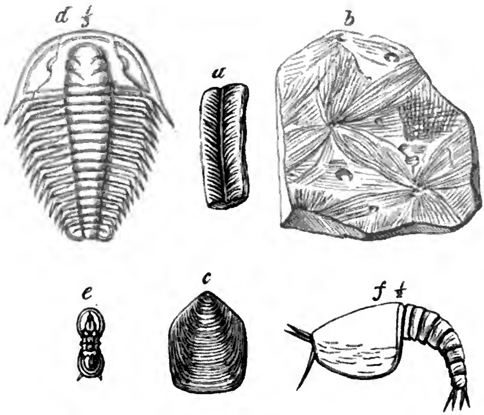
These beds are the Lingula flags of Professor Sedgwick and Mr. Davis, a term that has been adopted by the Geological Survey.

Characteristic Fossils of the Lingula Flags.—They contain a peculiar assemblage of fossils, of which the following may be taken as the most characteristic species :—

	Plant.
Cruziana semiplicata . .	Foss. gr. 2, *a*.*
	Polyzoa.
Dictyonema sociale . . .	Foss. gr. 2, *b*.
	Brachiopoda.
Lingula Davisii	Foss. gr. 2, *c*.
—— lepis.	
Orthis remota	Sil. Foss. 9, fig. 13.
	Crustacea.
Agnostus pisiformis . . .	Foss. gr. 2, *e*.
Conocephalus invitus . . .	Sil. Foss. 7, fig. 1.
Ellipsocephalus depressus . .	Sil. Foss. 7, fig. 2.

* The references here given point out where figures of the fossils named may be seen. "Foss. gr." refers to the groups of fossils figured in this work. "Q. J. Geol. Soc.," to the Quarterly Journal of the Geological Society of London ; "Sil. foss.," to the groups in the woodcuts in the 3d edition of "Siluria ;" "Sil. foss. pl.," to the plates in the same ; "Pal. foss.," to M'Coy's Palæozoic Fossils, published by Professor Sedgwick ; "Dec. G. S.," to the Decades of the Geological Survey ; "M'Coy Sil. foss.," to the Silurian Fossils of M'Coy, published by Sir R. Griffith, Bart. ; "Portl. G. R.," to Portlock's Geological Report." Other sources will be pointed out hereafter.

Hymenocaris vermicauda . .	Foss. gr. 2, *f.*
Olenus alatus.	
—— micrurus	Foss. gr. 2, *d.*
Paradoxides Forchammeri . .	Sil. Foss. 5, fig. 2.



Fossil Group No. 2.

Lingula Flag Fossils.

a. Cruziana semiplicata.
b. Dictyonema sociale.
c. Lingula Davisii.
d. Olenus micrurus.
e. Agnostus pisiformis.
f. Hymenocaris vermicauda.

These fossils, with some other trilobites, such as Sao, form the assemblage to which Barrande gives the name of the Primordial fauna.

Llandeilo Flags.—In each of the districts just mentioned as exhibiting the Lingula flags, there occur above them other beds of dark slate and sandy flags, with bands of sandstone occasionally, which cannot be separated physically from those below them, but contain a different group of fossils.

In South Wales these fossils are found in a well-marked group of rocks, consisting of finely laminated dark brown sandy flagstones, interstratified with black earthy slates, and containing calcareous bands that sometimes become regular limestones, and are still worked for lime. (*Murchison's Siluria*, p. 55, 3d ed.)

Similar rocks, likewise containing one (or two) bands of limestone,

occur also in North Wales, near Llanrhaidr yn Mochnant, the limestone forming, in one place, a conspicuous crag called Craig-y-Glyn.

In South Wales the beds are very well seen near the small town of Llandeilo Fawr, whence Sir R. I. Murchison named them the Llandeilo flags.

Characteristic Fossils of the Llandeilo Flags.—Characteristic fossils are abundant at the localities mentioned, and may frequently be procured in other places, wherever the group is exhibited.

In a quarry by Pont Ladies, near Llandeilo Fawr, I observed, in the year 1857, some dark gray carbonaceous shales, with beds of brownish sandstone, covered with black stains, like the remains of plants. Some of these were curved linear stripes, an inch wide, and two or three feet long; others were black concretionary nodules squeezed flat in dimple-like depressions, and some stains going through the beds like roots. They were associated with small corals, and covered by beds containing the trilobite named Ogygia Buchii; otherwise, the beds looked like Coal-measures with plant remains. They were possibly the tangled remains of sea-weeds, matted together in a bed of silt. They are interesting as giving us a possible clue to the existence of beds of anthracite, presently to be mentioned as occurring either in these rocks or the next succeeding group.

The following is a list of the more remarkable of the fossils found in this group, according to the classified list drawn up by Messrs. Salter and Morris, and given by Sir R. I. Murchison in the last edition of his Siluria.

Plants.

Chondrites regularis	Q. J. Geol. Soc., xi. p. 473.
Palæochorda major	Pal. foss. t. 1 A.
——— minor	Do. do.

*Actinozoa.**

Nebulipora favulosa	Sil. foss. 10, fig. 22.

Polyzoa.

Didymograpsus Murchisonii . . .	Foss. gr. 3, *a*.
Diplograpsus foliaceus	Sil. foss. pl. 1, fig 2.
Graptolithus sagittarius	Q. J. Geol. Soc., viii. p. 390.
Rastrites peregrinus	Foss. gr. 3, *b*.

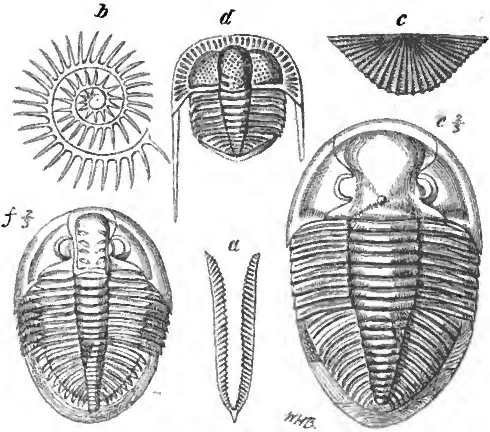
Brachiopoda.

Lingula attenuata	Sil. foss. 10, fig. 18.
Orthis alata	Foss. gr. 3, *c*.
Siphonotreta micula	Sil. foss. 10, fig. 17.

* All fossil Actinozoa are, of course, corals, since those without corals could scarcely be preserved in any way except as very obscure marks in rocks.

Conchifera.

Ctenodonta lævis . . . . Sil. foss., fig. 7.
Cucullela Anglica . . . . Sil. foss., fig. 8.



Fossil Group No. 8.
Llandeilo Flag Fossils.

a. Didymograpsus Murchisonii
b. Rastrites peregrinus.
c. Orthis alata.
d. Trinucleus fimbriatus.
e. Asaphus tyrannus.
f. Ogygia Buchii.

Gasteropoda.

Euomphalus Corndensis . . . Sil. foss., pl. 7.
Ophileta compacta . . . . Sil. foss. 38.
Riberia complanata . . . . Sil. foss. 8.

Pteropoda.

Maclurea Logani . . . . Sil. foss. 37, fig. 1.
——Peachii . . . . . Sil. foss 38, figs. 1, 2.

Cephalopoda.

Orthoceras Avelinii . . . . Sil. foss. 8, fig. 4.

Annelida.

Nereites Cambrensis . . . . Sil. foss. 42, fig. 3.
—— Sedgwickii . . . . Sil. foss. 42, fig. 2.
Trachyderma antiquissimum . . Malvern Proc., pt. 1.

Crustacea.

Æglina binodosa	Sil. foss. 8, fig. 6.
Ampyx nudus	Sil. foss. 46, fig. 7.
Asaphus laticostatus	Pal. foss., p. 170.
—— tyrannus	Foss. gr. 3, *e*.
Calymene parvifrons	Sil. foss. 9, fig. 4.
Illænus Murchisonii	Dec. G. S., 2.
Ogygia Buchii	Foss. gr. 3, *f*.
—— Selwynii	Sil. foss. 9, fig. 8.
Trinucleus fimbriatus	Foss. gr. 3, *d*.
—— Lloydii	Sil. foss. 10, fig. 7.

Bala and Caradoc Group.—The central part of Merioneth, around the town of Bala and its lake, affords the most typical example of these rocks. No hard line, however, can be drawn between them and the Llandeilo flags below. The black slates gradually become more sandy and gritty in texture, and more gray in colour, as we pass from the Arenig mountains towards Bala, so that over the black slates which we may assign to the Llandeilo flags, we get gray grits and slates with a total thickness of 5000 or 6000 feet, which we may class with the Bala beds. This thickness may be subdivided near Bala in the following way :—

(*See section fig.* 109.)

		Feet.
7.	Dark gray and black sandy slates	1200
6.	Hirnant limestone	10
5.	Gray sandy slates and grits	1500
4.	Bala limestone	25
3.	Gray sandy slates and grits	1400
2.	Bala ash bed	15
1.	Gray sandy slates and sandstones (say)	1350
		5500

No. 2. The Bala ash bed disappears in the hills to the south of the lake, although No. 4, the calcareous band called the Bala limestone, is distinctly traceable some miles farther south, dying away towards Dinas Mowddwy. The Hirnant limestone, No. 6, is only seen at one spot in the valley called Hirnant, three miles east of Bala, and another a mile or two north of it. As the beds are traced to the north-west and west, the Bala limestone retains its characters very persistently to the neighbourhood of Penmachno, and the ash bed, No. 2, is always found at about the same distance below it; another similar ash bed coming in,

in some places, about a thousand feet lower down. The occurrence of the two peculiar beds, the limestone and the ash below it, enabled me, when surveying the ground in 1846 and 1847, to trace them through a number of large dislocations across a broken country, from the valley of the Dee to that of the Conway.

To the west of the Conway valley the Bala beds become more and more invaded by igneous rocks, both contemporaneous and intrusive, and the ash beds join on to their parent bands of contemporaneous trap. The gray gritty slates become more purely black slate as we approach the town of Conway, though thick beds of brownish sandstone occur in them. Some of these sandstones are calcareous, and probably are on the same horizon as the Bala limestone, and they have below them two thick masses of felstone trap, separated by slate, which contains a peculiar bed of purple conglomerate; these felstones being, perhaps, the old submarine flows from which the ash beds of the Bala country derived their origin. This peculiar succession again made it possible to trace a series of faults with throws of two or three thousand feet across the hills south of Conway.

Farther south a great calcareous ash, forming the upper part of Snowdon, is considered by Professor Ramsay to be the representative of the Bala limestone; and enormous masses of igneous rocks spread below it with such complication as to have required years of labour on the part of my colleagues, Ramsay, Selwyn, and Aveline, to disentangle and lay them down on the published maps and sections of the Geological Survey. For not only were these great masses of igneous rocks of almost all varieties, and both of contemporaneous and intrusive character, but similar igneous masses occur on different geological horizons. The traps of Snowdonia, for instance, which lie in the Bala beds, die away towards the south-east into one or two thin ash beds, and gradually disappear altogether, while a similar series commence in that direction in the Llandeilo and Lingula flags, forming the hills known as the Arenigs, Aran Mowddwy, and Cader Idris. A corresponding change takes place simultaneously in the aqueous rocks, the Bala beds of Caernarvonshire more nearly resembling some of the Llandeilo beds of Merioneth than they do those of the proper Bala country. This changing series is, moreover, thrown into many abrupt curvatures over parallel anticlinal and synclinal axes, the radii of the curves being often some miles in length, while numerous and very large* dislocations traverse the rocks in almost every direction, leaving them, in some parts,

* One magnificent dislocation runs for nearly sixty-six miles from the lowland of Cheshire, through the Hundred of Yale in Denbighshire, down through Bala Lake, on the west side of Aran and east of Cader Idris, through Tal-y-llyn to the sea coast near Towyn. It dislocates the Carboniferous as well as the Lower Silurian rocks, and has an apparent downthrow to the north-west of 3000 or 4000 feet. It might be well called the Yale and Bala fault.

like a heap of disjointed ruins. The ruins, too, have been worn and gullied by denuding agencies, and are only to be examined here and there where they are uncovered by soil or vegetable growth. The difficulty of the task of determining the former order and arrangement of their several parts can only be appreciated by those who go over the ground with the geological maps and sections in their hands, and verify our interpretation of its structure.

If from the typical Bala county we proceed eastwards towards Shropshire, the Bala beds assume another phase. They lose most of their igneous rocks, and much of their slaty character, and pass into a formation of brown sandstone with occasional calcareous bands, in which form they were first described by Sir R. I. Murchison under the name of the Caradoc Sandstone. This name is derived from the hill called Caer Caradoc, near Church Stretton, the ancient caer or camp on which is named, after the old British King, Caradoc,* whom the Romans called Caractacus.

Characteristic Fossils of the Bala and Caradoc Rocks.—In the identification of a formation thus varying in lithological type, it is obvious that great assistance must be derived from its everywhere containing certain characteristic fossils, of which the following is a list of the most remarkable and abundant species :—

Polyzoa.

Didymograpsus caduceus . .	Q. J. Geol. Soc., ix. p. 87.
Diplograpsus bullatus . .	Q. J. Geol. Soc., vii. p. 174.
Fenestella capillaris . .	Portl. Geol. Report, p. 323.
Graptolithus Conybeari . .	Q. J. Geol Soc., viii. p. 390.
Ptilodictya acuta . . .	Sil. foss. 27.

Brachiopoda.

Discina (Orbicula) punctata . .	Sil. foss. 35, fig. 1.
Orthis elegantula	Foss. gr. 4, *b*.
—— flabellulum	Foss. gr. 4, *a*.
—— insularis.	
—— vespertilio	Sil. foss. 12, fig. 7.
Strophomena complanata . . .	Sil. syst., p. 636.

Conchifera.

Ctenodonta semitruncata . . .	Foss. gr. 4, *c*.
Modiolopsis expansa . . .	Foss. gr. 4, *d*.
Orthonota nasuta	Sil. foss. 12, fig. 12.

* In the pronunciation of Welsh words the accent is always to be thrown on the penultimate syllable, so that although in Shropshire the name is pronounced Carădoc, in Wales it would be called Carādoc.

Gasteropoda.

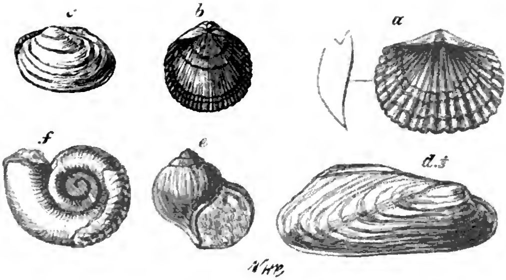
Cyclonema rupestre	Sil. foss. 37, fig. 4.
Holopæa concinna	Foss. gr. 4, fig. *e*.
Raphistoma equale	Sil. foss. 37, fig. 2.

Heteropoda.

Bellerophon nodosus	Sil. foss. 12, fig. 11.

Cephalopoda.

Lituites Hibernicus	Foss. gr. 4, *f*.
Orthoceras vagans	Sil. foss. 40, fig. 1.
Poterioceras approximatum . .	M'Coy. Sil. foss., p. 10.



Fossil Group No. 4.
Bala and Caradoc Fossils.

a Orthis flabellulum.
b Orthis elegantula.
c Ctenodonta semitruncata.
d Modiolopsis expansa.
e Holopea concinna.
f Lituites Hibernicus.

Echinodermata.

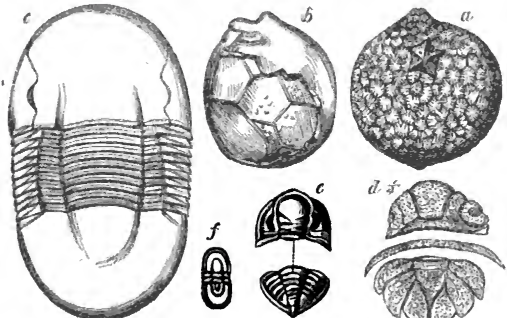
Agelacrinus Buchianus	Sil. foss. 30, fig. 6.
Echinosphærites aurantium . .	Foss. gr. 5, *a*.
—— Balticus	Sil. foss. 30, fig. 1.
Palæaster asperrimus	Sil. foss. 31, fig. 2.
—— obtusus	Sil. foss. 31, fig. 1.
Spheronites Litchi	Foss. gr. 5, *b*.

Annelida.

Crossopodia Scotica	Sil. foss. 42, fig. 4.
Trachyderma læve.	

Crustacea.

Acidaspis Jamesii	Dec. 7, t. b.
Æglina mirabilis	Sil. foss. 26, fig. 3.
Agnostus trinodus	Foss. gr. 5, *f.*
Asaphus Powisii	Sil. foss. 44, fig. 1.
Beyrichia complicata (*and Llandeilo*) .	Sil. foss. 10, fig. 10 *a.*
Calymene brevicapitata (*and Llandeilo*)	Sil. foss. 10, fig. 9.
Cheirurus clarifrons . . .	Sil. foss. 46, fig. 1.
Harpes Flanagani	Sil. foss. 46, fig. 4.
Illænus Bowmanni (*and Llandovery*)	Dec. G. S., No. 2.
Illænus Davisii	Foss. gr. 5, *c.*
Lichas Hibernicus	Foss. gr. 5, *d.*
Phacops apiculatus . . .	Foss. gr. 5, *e.*
Remopleurides dorso-spinifer . .	Sil. foss. 46, fig. 5.
Staurocephalus globiceps . .	Port. Geol. Rep., p. 257.
Trinucleus seticornis . . .	Sil. foss. 13, fig. 1.



Fossil Group No. 5.
Bala and Caradoc Fossils.

a Echinosphærites aurantium. *d* Lichas Hibernicus.
b Sphæronites Litchi. *e* Phacops apiculatus.
c Illænus Davisii. *f* Agnostus trinodus.

Lower Llandovery Sandstone.—In tracing the top of the Bala beds from North Wales into South Wales, certain beds of sandstone come in. In the neighbourhood of the little town of Llandovery, in Caermarthenshire, a bed of conglomerate occurs which may be taken as the base of a series of sandstones and shales, varying from 200 to 900 feet in thickness, which appear to belong physically to the Bala beds ; and to

be a mere local subdivision of that series. There is, however, rather a peculiar assemblage of fossils in them, some few peculiar to the group, some ranging into it from the Bala beds below, some ranging through it from the Lower into the Upper Silurian groups, and some commencing in it but proceeding from it into those groups. The fossils peculiar to the group, and therefore characteristic of it, are—

Polyzoa.

Nidulites favus	Sil. foss. 27.

Brachiopoda.

Atrypa hemispherica and crassa	Sil. foss., pl. 9.
Rhynchonella augustifrons . . .	Sil. foss. 48.
Orthis virgata.	

Some of those which range from the Bala beds below into the Lower Llandovery rocks, are the following :—

Petraia subduplicata	Sil. foss. 14.
Orthis Actoniæ	Sil. foss. 32.
Orthis caligramma	Sil. foss. 9.
Murchisonia simplex	
Homalonotus bisulcatus, ...	Sil. foss. 9.
Illænus Bowmanni	Dec. G. S. 2.
Lichas laxatus	Sil. foss. 44.

(See *Murchison's Siluria*, Third Edition, chapters v. and ix.; and *Horizontal Sections of Geol. Survey*, sheet 4.)

The group is connected with the rocks above by the occurrence of Pentameri, especially Pentamerus lens (Foss. gr. No. 6, fig. *d*), in great abundance, and by the following fossils :—

Petraia bina	Sil. foss. 52.
Atrypa marginalis	Sil. foss., pl. 9.
Leptæna scissa and transversalis	Sil. foss., pl. 9.

besides several that range from the Lower into the Upper Silurian groups.

It is probable that this group of rocks has in reality a much wider extension than has yet been assigned to it, and that it occupies more or less of the large tract of Lower Silurian ground which spreads in numerous undulations through Cardiganshire and the adjacent counties. The Plynlymmon group of Professor Sedgwick, in part at least, belongs to it, as appears from the list of fossils got at the Devil's Bridge, and determined by Mr. Salter, in which Atrypa crassa occurs. (See *Quart. Jour. Geol. Soc.*, vol. iii., p. 152.) Professor Sedgwick's Aberystwith group may possibly, perhaps, belong to the Bala beds below ; but the whole

country is so violently contorted, and thrown into such numerous and rapid undulations, that it is almost impossible to observe directly the order of superposition of the rocks, as appears from the fact of Professor Sedgwick's placing his groups below the Llandeilo flags instead of above them, which from Professor Ramsay's section, sheet 4, is obviously their true position.

Cumberland and Westmoreland—The Coniston group of Professor Sedgwick is doubtless in part equivalent to the Bala group. Whether the group below (his Chloritic slate and porphyry) ought to be placed with the Llandeilo flag or the Lingula flag, or either of them, is difficult to decide in the absence of fossil evidence.

His Skiddaw slate, again, in which fucoid impressions only have been found, may be either the lower beds of this period or might possibly be even of Cambrian age.

Scotland.—The rocks of the border Highlands, from Dumfries to the Lammermuir Hills belong to this period, probably both to the Llandeilo flags and the Bala group. They contain among others the following fossils :—Diplograpsus pristis, sextans, and teretriusculus ; Graptolites Sedgwickii, Wilsoni, Flemingii, and priodon ; Rastrites peregrinus ; Orthoceras politum, etc. Associated with numerous Graptolites is a band of Anthracite traceable for fifty miles through the county of Dumfries (*Harkness, Quart. Jour. Geol. Soc.*, vol. vii., p. 46). In other parts occur other fossils, the same as those of the Bala beds (*Murchison*, *Quart. Jour. Geol. Soc.*, vol. vii., p. 139, etc., and *Siluria*, Third Edition, chap. viii.)

The quartz rocks and gneissose flags of Sutherlandshire, with which beds of limestone are interstratified, belong to the same part of the period as the Llandeilo flags, as shewn by Sir R. I. Murchison in his recent papers in the *Quart. Jour. Geol. Soc.*, vols. xv. and xvii. The quartz rocks contain annelid tubes (*Scolithus linearis*) as do the quartz rocks of the Stiperstones in Shropshire (see fig. 107). The other beds, particularly the limestones, contain several Orthoceratites and other chambered shells, as also species of the univalve shells Maclurea, Ophileta, and Murchisonia, and other fossils. It is singular that some of the species are identical with those that occur in North America, and do not occur in Wales, and that the assemblage of fossils from this district has more of an American than of a British facies. (*J. W. Salter.*)

Ireland.—The Lingula flags are not yet known in Ireland. Their discovery would be of interest, as it would be of importance to know whether they would be conformable to the Cambrian or to the Lower Silurian rocks, or would, as in Wales, introduce conformity throughout the series.

The Lower or Cambro-Silurian rocks of Wicklow, Wexford, and Waterford are of the Bala and Caradoc age, as shewn by their fossils, with unfossiliferous beds below them, that may or may not belong to

the Llandeilo flags. They consist of dark blue or black, and gray flags, slates, and grits, sometimes, as in Wales, becoming purple, green, olive, etc. They contain many contemporaneous beds of trap and ash (felstone, etc.) like those of Wales, and one or two calcareous bands (very like the Bala limestone) near Courtown, and at Tramore.

Their thickness must be many thousand feet, but there are no good continuous sections sufficient to determine it exactly.

They repose on the Cambrian rocks below, quite unconformably, stretching directly across the ends of the beds, and coming into contact with different portions of the lower rocks.—(*See Section fig.* 82, p. 295.)

The fossils are found only in the upper part of the series in the neighbourhood of the traps,* and calcareous bands, and the exact relations of the lower beds are accordingly unknown.

The island of Lambay, and the promontory of Portraine in county Dublin, also expose slates and calcareous bands belonging to this period, and full of characteristic Bala fossils, as do also the hills of the Chair of Kildare. (See explan. of sheets 102, 112, and 119 of the Maps of the Geological Survey of Ireland.)

Another great tract of apparently similar beds stretches from the centre of Ireland (Cavan, etc.), to the coast of Down. Among these, however, a portion certainly belongs to the Llandeilo flags, as near Bellewstown, on the confines of Dublin and Meath, an assemblage of the following fossils characteristic of that group were collected years ago by J. Flanagan :—

Didymograpsus Murchisonii.
Diplograpsus pristis.
Graptolites Nilsoni.
———— sagittarius.
Siphonotreta micula.
Lingula, resembling Davisii ;
and another species.

At a place called Kilnaleck, in the county Cavan, a band of anthracite occurs in these rocks, and may be traced also in county Down, as if striking from Dumfries. It occurs again nearly in the same strike at a place called Upper Church, in county Tipperary, some miles west of Thurles (See Explanation of Sheet 145 of the Maps of the Geological Survey), in a large area of Cambro-Silurian rocks, in which also Graptolites and other fossils have been found by Mr. A. B. Wynne of the Geological Survey of Ireland. These form the central mass of

* The eruption of igneous rocks at the bottom of the sea, though doubtless occasionally destructive of animal life at the moment, seems generally favourable to its development during the period. Contemporaneous trap rocks have often highly fossiliferous beds intimately associated with them.

a group of hills which may be called the Keeper group, and precisely similar beds, abounding also in Graptolites, occur in the Arra mountains and Slieve Bernagh to the west of it, where they have been examined by Mr. G. H. Kinahan. Beds believed to be of the same age form the heart of the Galty mountains.

In the Cratloe Hills north of Limerick, beds occur that probably belong either to the Bala beds or to the Lower Llandovery group (though one patch contained fossils apparently of Upper Llandovery age), and this is the case also with beds which occur in Caherconree mountain and the Annascaul valley, west of Tralee, in county Kerry. The rocks of the hill called Knockshigouna also, to the west of Roscrea, are probably of Llandovery age. In the north of Ireland the Lower Silurian rocks of Pomeroy and other places yielded a rich harvest of fossils to the labours of the geological branch of the Ordnance Survey under (Captain, now) General Portlock.—(See his Report on the Geology of Londonderry, etc.)

On the flanks of the Dublin and Wicklow granites, the Lower Silurian slates and grits are greatly metamorphosed into mica and other schists, and occasionally into gneiss, and are often full of crystals of andalusite, staurolite, schorl, feldspar, and other minerals.

Other metamorphic tracts in the north-west of Ireland may be also composed of metamorphosed Lower Silurian rocks.

Bohemia.—Stage C, Argillaceous schist, and stage D, Quartzites, etc., of Barrande, are of this period. Stage C corresponds to the Lingula flags, but is more fossiliferous, containing twenty-seven species of Trilobites alone. Stage D certainly corresponds to the Bala and Caradoc group, so that the Llandeilo flag, as now understood, is probably divided between stages C and D. Stage C is characterized by what Barrande calls his Primordial fauna, the Trilobites of which belong to the genera Agnostus, Arionellus, Conocephalus, Ellipsocephalus, Hydrocephalus, Paradoxides, and Sao, genera which are entirely confined to that zone, except one species of Agnostus. Stage D includes the second fauna of Barrande, which contains 81 species of Trilobites belonging to the genera Acidaspis, Æglina, Ampyx, Asaphus, Cheirurus, Illænus, Ogygia, Trinuclus, and 22 others.

Scandinavia.—M. Angelin's Regio A. Olenorum and Regio B. Conocoryphарum, consisting of aluminous schists and limestone, are approximately equal to stage C of Barrande, and therefore approximately equal to the Lingula flags.

The Scandinavian beds contain 71 species of Trilobites of the same peculiar genera as the Bohemian beds, but without one identical species.

Angelin's regions—B C, Ceratopygarum (aluminous schist and black limestone) ; C, Asaphorum (gray and reddish impure limestones) ; and

D, Trinucleorum (marly schists with calcareous concretions)—are together approximately equal to stage D of Barrande.

There are 81 species of Trilobites in the Bohemian beds D, and 176 in those of Scandinavia, B C, C, and D. The genera are the same in both countries, and the species nearly allied; but there is said to be not one species common to the two districts.—(*Barrande's Parallèle entre les depôts Siluriens de Bohême et Scandinavie.*)

It is yet doubtful whether these specific differences, existing together with generic identities, be due to a want of exact synchronism in the age of the beds, or to the geographical distribution and limitation of the life of the period; whether, in fact, they are the result of time or space. It is perhaps most probable that they are contemporaneous, or nearly contemporaneous groups, deposited in seas separated either by intermediate lands or by impassable depths, or traversed by currents from different sources.

North America.—According to Prof. H. D. Rogers, the following is the series of the Lower Silurian rocks of Pennsylvania:—

		Feet.
Hudson River Group.	11. Lorraine shale and sandstones	2000
	10. Utica slate	
	9. Trenton limestone	500
Black River Group.	8. Black River limestone	2500
	7. Birdseye limestone	
	6. Chazy limestone	
	5. Calciferous sandstone	100
Potsdam Group.	4. Upper Primal slate	700
	3. Potsdam sandstone	700
	2. Lower Primal slate	1200
	1. Conglomerate with quartzose, feldspathic, and slaty pebbles	150

Characteristic Fossils.—Rogers says that 1 and 2 are unfossiliferous. No. 3, the Potsdam sandstone, contains a Lingula, from which it is supposed to be equal to Lingula flags. No. 4 contains Fucoids only.

Nos. 5 to 8, or the Black River group, have about 100 species of fossils, and are apparently nearly equivalent to the Llandeilo flags.

The Hudson group has a very large assemblage of fossils, of which not more than 2 or 3 per cent are found in any higher bed. They contain Trinucleus concentricus, Orthis striatula and biforata, etc., and are therefore supposed to be very nearly the equivalents of the Caradoc sandstone and Bala beds.

The beds described by Mr. Dale Owen are supposed to be an extension and development of the Potsdam sandstone, in the country west of Lake Michigan.

They contain an abundance of fossils down to the very base, consisting of Lingula, Orbicula, Obolus, Trilobites of several peculiar forms called Dikelocephalus, etc., and of compressed subconical bodies, resembling Cephalopoda, but probably not belonging to them. The fossils are locally in immense abundance, although not numerous in species. They are most probably of the age of the Lingula flags.

Dr. Bigsby, in *Quart. Jour. Geol. Soc.*, vol. xiv., has a most elaborate paper on the Palæozoic rocks of the State of New York, with full descriptions of the rocks, and lists of the fossils. The Potsdam sandstone has no slate above or below it as in Pennsylvania, and other slight differences occur in the various grouping and thickness of the rocks.

In Newfoundland, I formerly described four groups of beds as making the peninsula of Avalon and other parts of the island, under the following provisional designations :—

Upper slate formation.	Belle Isle shale and gritstone. Variegated slate.
Lower slate formation.	Signal Hill sandstones. St. John's slate.

I was not lucky enough to detect any fossils in them, bnt Mr. C. Bennett has subsequently been so fortunate as to hit upon a thin layer of trilobites, of the genus Paradoxides (named P. Bennettii by Mr. Salter), in the slates of the west side of St. Mary's Bay. These slates belong to the group I called the St. John's slate, which is covered conformably by the Signal Hill sandstone. The Variegated slate group, on the other hand, passes up into the Belle Isle shale and gritstone, and near Brigus Harbour, in Conception Bay, may be seen to rest unconformably on the St. John's slate.—(*Report on the Geology of Newfoundland*, Murray, 1843, p. 79.)

The Messrs. Rogers have recorded the discovery of numerous fine specimens of Paradoxides Harlani, at Braintree, near Boston ; and Sir W. Logan and Mr. Billings, of the Canadian Survey, have lately described a series of fossiliferous limestones at Point Lewis, opposite Quebec, in one of which (probably the lowest) trilobites of the genera Conocephalus, Dikelocephalus, etc., occur, with a Lingula and other fossils, thus shewing the probable existence of the Lingula flag group, while the other limestones contain fossils more like the fauna of the Bala beds.

Dr. Emmonds long ago described a great series of rocks in the United States under the name of the Taconic system, to which I believe a good deal of injustice has been done under the influence of preconceived views. The rocks were greatly disturbed and contorted, but according to Emmonds have a vast thickness, and are covered uncon-

formably by the Calciferous sandstone ; the base, according to Rogers, of the Black River group, which is supposed to be equal to the Llandeilo flags.

Dr. Emmonds now divides his Taconic system into two parts—an Upper, consisting of Black slates and other beds, including the Hoosick slates, with a total thickness of 25,000 feet ; and a Lower, containing the Stockbridge limestone, and other beds resting on brown grits and quartz rocks, having a total thickness of 5000 feet. In the Black slate, forming the uppermost of this series, are a number of trilobites, some of which Barrande refers to Paradoxides and Peltura (or Olenus), and believes them to belong to his so-called Primordial fauna.—(Paper by M. Barrande, entitled, " Documents Anciens et Nouveaux sur le Faune Primordiale de la System Taconique en Amérique. Bulletin de la Soc. Geol. de France, Fevrier 4th, 1861.)

It is possible, perhaps, that the lower * part of the Taconic system belongs to the Cambrian period, and perhaps is the same with the Huronian group of Sir W. Logan.

Life of the Period.

We have already examined the scanty traces of organic life which have hitherto been detected in the rocks of the Cambrian period, and seen reason to doubt that those can be the records of the first appearance of life upon the globe, though they are undoubtedly the earliest of which we have any knowledge. The traces of life in the earliest part of the Cambro-Silurian period are likewise few and scanty, and belong to animals quite as widely separated from each other in the scale of existence as are those of the Cambrian period.

We may remark, in the first instance, that none of the undoubted Cambrian forms have hitherto been found in any Cambro-Silurian formation.

Secondly, It is remarkable that while the Cambrian Oldhamia bears, according to Dr. Kinahan, a striking resemblance to the living Sertularia, so the Lingulæ of the Lingula flags are wonderfully like shells of the same genus living at the present date. I have myself gathered from the mud of a little bay near Cape York, in Torres Straits, living Lingulæ, which to all appearance differ from those of the Lingula flags only in being a little smaller and narrower in form.

While, however, this is the case with the Brachiopods, most of the

* It does not appear clearly that Dr. Emmonds's identification of the Upper and Lower parts is certainly correct ; but if the fossils really occur in the Upper part only, and there be a great thickness of unfossiliferous beds really below them, then these, or some of them, may well be Cambrian.

crustacea belong to an order (Trilobites), which became totally extinct at a very early period of the earth's history; and not only so, but the very genera which existed during the time when the Lingula flags were deposited all died out before the close of the Cambro-Silurian period, and most of them even became extinct in this early part of the period itself.

Another observation worthy of notice is, that as yet no form of Graptolite has been recorded as having been found anywhere in the Lingula flags, although the kind of rock is often such as that in which Graptolites occur abundantly in the next succeeding groups.

The Graptolites are linear bodies, with a slender stem and small notches or indentations arranged along one or both sides of it. They are sometimes 18 or 20 inches in length without any definite termination, at others they terminate in one direction in a sort of spike without notches. They were at one time believed to be allied to the Virgularia or Seapens (whence the name of Graptolite, from *grapho*, to write), belonging to the Cœlenterata, but are now supposed by Professor Huxley to have been Polyzoan Mollusca.

The Trilobites were Crustacea somewhat analogous to the Limulus or King Crab of tropical seas, a kind of crab with a large shield covering the body, and small, soft, inconspicuous legs or feet. It is probable that the body and under parts of the Trilobites were entirely soft, as nothing but the shields are found in a fossil state, though these are in some places very abundant. They are named from the shield being divided longitudinally into three lobes or divisions, more or less marked in the different genera. It is also divisible into three parts: head, thorax, and pygidium or tail piece, each of which shew more or less of the trilobed division. The thorax is often composed of several distinct rings, which in some were movable, so that the animal could curve itself just as the lobster curves the tail beneath the body.

Lingula Flags.—The list given previously as that of the *characteristic* fossils of the Lingula flags, contains in reality almost the whole assemblage of fossils that have hitherto been described as found in them in the British Islands.

Llandeilo Flags.—In proceeding to the next group, namely, the Llandeilo flags, we find traces of life becoming more abundant and belonging to a greater variety of forms. Some obscure plants have been described like cords in shape, and therefore probably sea-weeds. Some corals, also, appear, and among them the beautiful Chain coral (Halysites catenularius, Sil. foss. 19, 28, and pl. 40), which is found still more abundantly in newer groups, ranging up as high as the Wenlock limestone, where it is most abundant of all.

The Graptolites are very numerous. Three species of Didymograpsus or twin Graptolite, like two single Graptolites united at the base,

occur only in the Llandeilo flags, while one is only found in the Bala beds. No less than nine species of double Graptolite (Diplograpsus, or those having cells on both sides of the stem) are found in the Llandeilo flags; of which one has been found also in the Bala beds, and one other has been found only in that group. The genus Rastrites is perhaps peculiar to the Llandeilo flags. Of the genus Graptolithus there are six species in the Llandeilo flags, one of which is found in the Bala beds; and there are six others in those beds, of which one ranges into the Ludlow group of the next period.

Of Brachiopodous shells there are five species of Lingula (different from those of the Lingula flags), which are found only in the Llandeilo group, nine species of Orthis, of which three are peculiar to the group, and one (O. Actoniæ) which ranges into the Llandovery rocks, while three species—namely, *biforata*, *calligramma*, and *elegantula*—survived even to the period when the Wenlock beds were deposited. A Spirifer, called *insularis*, signalizes the first appearance of this genus, and the genus Leptæna gives the first indications of its existence in the species *tenuicincta*, which is found also in the Bala beds and *sericea* which ranges into the Wenlock.

The Conchifera, or ordinary bivalves, and the Gasteropods, are represented by the genera and species mentioned at p. 446.

The genus Bellerophon makes its appearance in the Llandeilo flags, as do also two genera of Pteropoda—namely, Maclurea and Theca—and two of Cephalopoda, Orthoceras, and Oncoceras.

Passing from the Mollusca to the Annulosa, we find in the Llandeilo flags several markings attributed to Annelida, of which one kind, assigned to a genus called Nereites, is peculiar to that group.

The Crustacea exhibit numerous trilobites. Of these, the genera Angelina, with two species; Ogygia, with five species; and probably also the whole genus Olenus, with its five species, are peculiar to the Llandeilo flags; the genus Æglina has three species in the Llandeilo flags, and one other in the Bala beds; of Agnostus, the species *M'Coii* is Llandeilo only, *pisiformis* both Lingula and Llandeilo, and *trinodus* is peculiar to the Bala beds. Asaphus shews two species in Llandeilo flags, and four others in the Bala beds, the genus then becoming extinct. Beyrichia has one, *complicata*, common to the Llandeilo and Bala beds, and four others peculiar to the latter, while there are three more in the Upper Silurian rocks. The genus Calymene also commenced its existence during the deposition of the Llandeilo flags, two species, *duplicata* and *parvifrons*, being found in them only; one, *brevicapitata*, both in them and the Bala beds; while others belong to Upper Silurian groups. Of the genus Cheirurus, one, *Sedgwickii*, is found only in the Llandeilo flags; four are found only in the Bala beds, while one other ranges from

them into the Wenlock group. Cybele has one species, *verrucosa*, common to the Llandeilo and Bala beds, and one, *rugosa*, only in the latter. Homolonotus is first seen in the Llandeilo beds in a species called *Vulcani*, two others appearing in the Bala beds, and two more only in the Upper Silurian rocks. The genus Illænus has two species *Murchisonii* and *perovalis*, in the Llandeilo flags; two others in the Bala beds only, one, namely, I. *Bowmanni*, common to those beds and the Llandovery rocks; while another makes its appearance in the Upper Silurian period. Stygina has one Llandeilo species, namely, *Murchisonæ* (named after Lady Murchison), and another, *latifrons*, in the Llandovery rocks. Of the genus Trinucleus, five species are peculiar to the Llandeilo flags, one common to them and the Bala beds, and two found only in the latter.

Bala Beds.—When we come to the Bala beds themselves, fossils become still more numerous and varied.

No distinct Plants have yet been recorded from them.

Two Sponge-like bodies, called Acânthospongia and Clione, have been noted; and one, Stromatopora striatella (Sil. foss. 51), makes its first appearance now; but is still more abundant in the Wenlock limestone.

Of Corals, we find the Favosites alveolaris, which ranges into the Ludlow rocks, the Halysites catenularius, already mentioned, six species of Heliolites, four ranging into Upper Silurian groups, while two, *favosus* and *inordinatus* (Sil. foss. 27), are confined to the Bala beds. Of Nebulipora, two species are peculiar; while Omphyma turbinatum ranges from Bala to Wenlock rocks. Of the genus Petraia none are peculiar; all the species ranging into the Llandovery, and one into the Wenlock rocks.

Of the class Polyzoa, we get two double Graptolites from the Llandeilo flag, besides those already mentioned at p. 449 as characteristic of the Bala beds, and three other species of single Graptolites, of which one, namely, G. priodon, ranges into Upper Silurian. There are also five species of Fenestrella, three of which are also Wenlock species; one of Glauconome, also a Wenlock species; and five species of Ptilodictya, two of which also range into the Upper Silurian.

Brachiopoda are very numerous; the genera Atrypa, Crania, Discina (Orbicula), Rhynchonella, Strophomena, and Trematis, make their first appearance; Crania, Discina, and Rhynchonella, having existed ever since. Atrypa marginalis (Sil. foss., pl. 9) ranges to Wenlock; Crania divaricata (Sil. foss. 35) is peculiar, as are also five species of Discina, as the genus Orbicula is now called. There are six species of Leptæna, including the two which range into the Bala from the Llandeilo beds, and two which range from Bala to Wenlock rocks; three species of Lingula, supposed to be peculiar; and no less than

twenty-eight species of Orthis, of which fifteen are peculiar to the Bala beds, two are common to them and the Llandeilo, four range from the Llandeilo through the Bala into the Upper Silurian, while five or six others extend into the Upper Silurian from the Bala beds. There are also two species of Orthisina peculiar; five species of Rhynchonella, of which three are peculiar; and twelve of Strophomena, of which seven are peculiar; while the others, among which is the very common shell S. depressa, range into the Upper Silurian. It is remarkable that there are no Pentameri at all, and that the only Spirifer is the Spirifera insularis from the Llandeilo flag.

Conchifera also, of which only two species are known in earlier rocks, now become rather numerous, the genus Ambonychia (a group of bulging Aviculæ) having six species peculiar to the Bala beds, while Cardiola semiruguta, Lyrodesma plana (Sil. foss. 36), and Orthonota nasuta (Sil. foss. 12), are equally confined to them. The singular genus Conocardium, afterwards so highly developed in the Carboniferous period, shews one small species, C. dipterum (Sil. foss. 36). The genus Ctenodonta (allied to Nucula) has twelve species, Modiolopsis seven species, and Mytilus (so abundant in the present seas) also exhibits two ancient species in the Bala beds.

Gasteropoda also shew a great increase of species and genera, since mention has been already made of all which previously existed, while in the Bala beds Cyclonema (a sub-genus of Turbo), Holopæa (allied to Trochus), Holopella (like a Turritella), and Macrocheilus (somewhat like Buccinum or Pyramidella), come into existence and exhibit several peculiar species. There are nine species of Murchisonia, of which three range into the Llandovery beds, and several species of the long extinct genera Ophíleta, Raphistoma, and Trochonema, while Pleurotomaria trochiformis is a species of a genus that long survived the period, and Patella Saturni belongs to a genus most abundant at the present day. Some of these univalve shells, which resemble in form our Turbo or Trochus, were believed by Edward Forbes to be most probably oceanic shells floating like our existing Ianthina.

Of the Heteropodous or Pteropodous univalves, the Bala beds afford three peculiar species of Bellerophon, the only genus of which we have species in earlier beds, while of the genera now seemingly first commencing we have two species of Pterotheca, one Conularia, C. elongata (Sil. foss. 39), and one Ecculiomphalus, E. Bucklandi (*ib.*)

Passing to the highest group of the Mollusca, namely, the Cephalopoda, we find one species of Cyrtoceras, five of Lituites, and one of Poterioceras, genera now apparently first coming into existence, while there are nineteen species of Orthoceras, a genus of which two species had already appeared in the Llandeilo beds.

If we turn from the Mollusca to the Annulosa, we find the class

Echinodermata now making its first appearance. Among these are two genera of star fishes, Palæaster with two species, *asperrimus* and *obtusus* (Sil. foss. 31), and Protaster with one species *Salteri* (Geol. J. 1, p. 20). These genera do not differ very greatly from some living star fishes. There is also the order Cystidea, allied to Encrinites, which became, however, entirely extinct at the close of the next period; of this we find the following genera and species—Agelacrinus Buchianus (Sil. foss. 30), a form of which only one example has been found in Europe, though it occurs also in America; five species of Echinosphærites, three of Hemicosmites, and four of Sphæronites, genera peculiar to the Bala beds, and two species of a crinoid genus, probably Glyptocrinus.

In the class Annelida we get several forms referred to genera called Crossopodia, Lumbricaria, and Trachyderma, and two species of Tentaculites, namely, *anglicus* (Sil. foss. pl. 12), which also occurs in the Llandovery rocks, and *ornatus* (Sil. foss. pl. 16), which ranges into the Wenlock.

The Trilobites become remarkably abundant, and are, indeed, with the Cystidea perhaps the most striking and important of all the fossils of the Bala beds. The genus Acidaspis comes into existence exhibiting seven species, of which one ranges into the Wenlock. Æglina has one species, *mirabilis* (Sil. foss. 26), and then becomes extinct. Agnostus has two species, the one figured at p. 451, and *limbatus* (Sil. foss. 44), and likewise dies out. The genus Ampyx has three species; Asaphus has four and dies out; Beyrichia has five species; Calymene has three, including the common C. Blumenbachii, so abundant in the Wenlock limestone; Cheirurus has also five, of which one, *bimucronatus* (Sil. foss. 64, and pl. 3), ranges to the Wenlock group. Cybele has two and becomes extinct; Cyphaspis commences with one, *megalops* (Sil. foss. 64), that ranges to the Ludlow rocks; Encrinurus also commences with three species; and Harpes both commences and dies out with two species, *Dorani* and *Flanaganni* (Sil. foss. 46). Homolanotus also commences with two species, one of which ranges into the Llandovery rocks; Illænus has three species, of which *Davisii* is figured at p. 451, and *Bowmanni* (Dec. G. S. 2) ranges into the Llandovery rocks. Lichas commences with six species, of which one, *Hibernicus*, referred also to Bronteus and Nutainia genera now suppressed, is figured at p. 451. Phacops also commences, shewing eleven species, one of which, *apiculatus*, is figured at p. 451. Remopleurides both commences and dies out, shewing seven species. Sphærexochus mirus extends from the Bala beds to the Wenlock, as does one species of Staurocephalus, the other *globiceps* being confined to the Bala group. Stygina shews one species, *latifrons* (Sil. foss. 26), and Trinucleus two species, of which *seticornis* (Sil. foss. 13) is one, besides the *concentricus* from the Llandeilo flags; both genera then become extinct. The genera Am-

phion and Tiresias also appear and die out with a single species each.

In the Lower Llandovery beds the genus Pentamerus makes its first appearance with other fossils, but their discussion had better be deferred to the description of the rocks of the next period.

M. Barrande, to whose admirable researches in Bohemia, and the works that have sprung from them, it is impossible to give too high a praise, proposes the term Primordial fauna for the assemblage of fossils found in the Lingula flags of Wales, and their corresponding beds in other parts of the world. He uses the term "Second Fauna" for the fossils of the Llandeilo flags, and the Bala and Caradoc group; and "Third Fauna" for those of the Upper Silurian period. These terms seem to be unfortunately chosen. The term *primordial* involves the idea of its being not only the earliest fauna we know, but the earliest that ever existed—a fact it would be impossible to establish even if no earlier fossils were ever to be found. That it is not true is shewn by the existence of the Cambrian fossils previous to it. It is therefore to be regretted that M. Barrande has shackled himself with such a nomenclature as allows of no retrograde expansion, and scarcely permits of intercalation. No one, I think, can really entertain the belief that the few scanty species yet found in these early rocks are anything but a miserable minority of the living beings that existed during the period of their deposition.

The term Azoic is one also that should be at once discarded, since no one is warranted in describing a period as Azoic merely because no fossils have yet been found in the rocks belonging to it.

Of those beings that lived during the Cambro-Silurian period comparatively few, perhaps, have been preserved, and even of those that have been preserved we cannot believe that anything like all have yet been discovered. While, then, we refuse to base a positive belief on merely negative evidence, we nevertheless can only draw conclusions from what we know; and as it is true that up to the present time no fragment of any living being that we may class as higher in the scale of creation than an Orthoceras, or a Trilobite, has yet been found, we cannot assert that any higher animal hitherto existed. No bone or scale of fish, or any other vertebrate animal, has hitherto been established as found in any Lower Silurian rock. So long as this remains the case, we are, of course, not warranted in supposing vertebrate life to have come into existence on the globe.

The following is a list of the principal generic forms which first came into existence, so far as is yet known, during this period, those marked with an asterisk not being known to have survived it :—

Plants, *Chondrites, *Cruziana, *Palæochorda, *Trichoides.
Spongidæ, *Acanthospongia, Cliona, Stromatopora.

Actinozoa, Favosites, Halysites, Heliolites, Nebulipora, Omphyma, Petraia, Pyritonema, Sarcinula, Stenopora, Strephodes, Syringopora.

Polyzoa, Diastopora, *Dichograpsus, *Dictyonema, *Didymograpsus, *Diplograpsus, Fenestrella, Glauconome, Graptolithus, Protovirgularia, Ptilodictya, *Rastrites.

Brachiopoda, Atrypa, Crania, Discina (Orbicula), Leptæna, Lingula, Obolus, Orthis, Orthisina, Rhynchonella, Siphonotreta, Spirifera, Strophomena, *Trematis.

Conchifera, Ambonychia, ? Cardiola, Conocardium, Ctenodonta, Cucullela, Lyrodesma, Modiola, Modiolopsis, Mytilus, Nucula, Orthonota, Pterinæa.

Gasteropoda, Cyclonema, Euomphalus, *Holopæa, Holopella, Macrocheilus, Murchisonia, *Ophileta, Patella, Pleurotomaria, Raphistoma, *Ribeiria.

Heteropoda and Pteropoda, Bellerophon, Conularia, Ecculiomphalus, *Maclurea, Pterotheca, Theca.

Cephalopoda, Cyrtoceras, Lituites, Orthoceras, *Oncoceras, Poterioceras.

Echinodermata, *Agelacrinites, *Echinosphærites, Glyptocrinus, *Hemicosmites, Palæaster, Protaster, Rhodocrinus, *Sphæronites.

Annelida, *Aphrodita, Arenicola, Crossopodia, *Lumbricaria, *Myrianites, *Nemertites, *Nereites, Serpulites, Tentaculites.

Crustacea, Acidaspis, *Æglina, *Agnostus, *Amphion, Ampyx, *Angelina, *Asaphus, Beyrichia, Calymene, Cheirurus, *Conocephalus, *Cybele, Cyphaspis, *Cyphoniscus, *Cytheropsis, Dithyrocaris ? *Ellipsocephalus, Encrinurus, *Harpes, Homalonotus, *Hymenocaris, Illænus, Leperditia, Lichas, *Ogygia, *Olenus, *Paradoxides, Phacops, *Remopleurides, Sphærexochus, Staurocephalus, *Stygina, *Tiresias, *Trinucleus.

CHAPTER XXVIII.

UPPER SILURIAN PERIOD.

Typical Rocks.

If we return to the neighbourhood of Llandovery in South Wales, we shall find that over the sandstones already described as the Lower Llandovery beds, certain other sandstones come in, not very different from them in lithological character, and having some fossils in common with them. They vary there from 300 to 700 feet thick. They are separated from the Lower Llandovery, because they rest uncomformably upon them and overlap them, so that when traced towards the north they rest directly on the Bala beds (see Geol. Survey Maps, sheets 41 and 42, and Horizontal Sections, sheet 4). They are called the Upper Llandovery rocks, and they form the true base of the Upper Silurian series. That they are physically distinct from the Lower Llandovery is shewn not only by the local unconformity near Llandovery, where they are both present, but also by the fact that wherever the Lower Llandovery rocks are to be seen they adhere to and form the top of the Lower Silurian series, while wherever the Upper Llandovery are seen, they lie conformably beneath the rest of the Upper Silurian series, but are distinctly and often widely unconformable to the Lower Silurian.

It is indeed a remarkable fact, that wherever the Upper Silurian and Lower Silurian rocks are found together in anything but a horizontal position, there is an unconformable break between them. This is often a clear discordance in the lie of the rocks, so that they obviously dip in different directions or at different angles. But even where there is no apparent unconformability, and they dip and strike apparently together, the unconformity may eventually be discovered by different parts of the two series being in apposition in different places.

In parts of Shropshire this unconformity is not very striking, and there it so happens that the Bala and Caradoc beds consist of yellow and brown sandstones of very much the same character as the Llandovery beds, so that they were originally classed together under the name of the Caradoc sandstone. They had in like manner been called Caradoc on the west flank of Malvern, at Woolhope, and May Hill, and elsewhere. Professor Sedgwick was the first to point out the necessity

for separating these beds from the Lower Silurian, and proposed the name of the May Hill Sandstone for them (Geol. Jour., vol. ix., p. 215). Messrs. Aveline and Salter afterwards traced the unconformity between them and the Caradoc beds in Shropshire (Q. J. Geol. Soc., vol. x., p. 62), and their presence was afterwards recognised as the base of the Upper Silurian series in many other localities. After several names, such as Upper Caradoc, Pentamerus beds, Wenlock grit, etc., had been proposed and discarded, they now seem to have been settled as Llandovery rocks (*Siluria*, 3d. edition). To this, however, the name "May Hill Sandstone" should be added as a second title, since Professor Sedgwick, with M'Coy, first indicated their distinctness, although they did not work it so thoroughly out as was afterwards done by the Geological Survey.

In the Llandovery country these Upper Llandovery or May Hill rocks are succeeded by a group of pale gray, smooth, fine-grained slate rocks, to which the name of "Tarannon shales" has been given by Professor Ramsay, from the valley and river of that name, between Llanidloes and Dinas Mowddwy, where they attain a thickness of 600 feet. These pale slates sometimes change into a bright red. They may be traced from South Wales into North Wales, and followed through all the undulations of the rocks down to Conway, forming either with or without the Upper Llandovery beds a marked line of separation between the Lower and Upper Silurian districts. This little group had likewise not escaped the observation of Professor Sedgwick, who describes them under the name of the Rhayader slates, as "pale, leaden-gray, passing into greenish gray," with "beautiful cleavage planes." He at first gave them their true place, at the lower part of the Upper Silurian, though afterwards he was led, by the wonderfully contorted condition of the country, to class them with the Lower Silurian. (Q. Jour. Geol. Soc., vol. iii., p. 153.)

In North Wales these pale Tarannon shales or Rhayader slates are succeeded by a great sandstone formation, consisting of coarse brown sandstone, with occasional quartzose conglomerates, and interstratified with black slates, and passing up into brown flags and slates, which were called Denbighshire sandstone and flag by Mr. Bowman and Professor Sedgwick, a name adopted by the Survey. Over these are other beds of shale or slate, and flag or sandstone. The beds which lie next above the pale Tarannon shales contain few fossils, but those are of species that shew them to belong to the Wenlock group presently to be described.

If instead of following the Llandovery rocks into Montgomery, Merioneth, and Denbigh shires, we proceed into Shropshire, we find in the country between Church Stretton and Wenlock the Upper Llandovery beds covered by a great thickness of shale, purple near the

bottom, but gray in the upper parts, which forms the lower portion of the north-western slope of a long straight ridge, known as the "Wenlock Edge," from the little town of Much Wenlock, which lies near its north-east termination. This Edge is capped by a band of limestone, 100 or 200 feet thick, running for fifteen miles in an unbroken line, and dipping south-east under other soft brown shales and sandstones, which make a second small, gently sloping, ridge, capped by another limestone band, and this dips beneath a second series of brown sandstones, mudstones, and shales, which gradually pass up into a series of red flags and sandstones (see section, fig. 110).

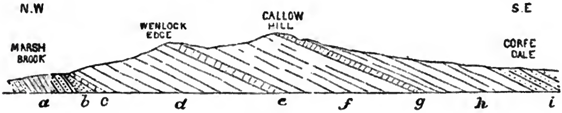


Fig. 110.

Section across Wenlock Edge, reduced from sheet 34 of Horizontal Sections, Geological Survey. Drawn by W. T. Aveline.

Length of Section about four miles.

	i.	Red Sandstone, supposed base of Old Red Sandstone.	
Ludlow rocks	*h.*	Upper Ludlow—Gray and brown shale and sandstone .	900 feet.
	g.	Concretionary limestone (Aymestry)	150 "
	f.	Lower Ludlow—Gray and brown calcareous sandy shale	900 "
Wenlock rocks	*e.*	Gray nodular concretionary limestone (Wenlock and Dudley limestone)	150 "
	d.	Gray and brown sandy shale, often concretionary (Wenlock shale)	1400 "
	c.	Limestone (Woolhope and Barr)	50 "
Llandovery . .	*b.*	Sandstone and conglomerate (Llandovery).	
Lower Silurian	*a.*	Bala beds or Caradoc Sandstone.	

As the result of the facts observed in this section and others similar to it, such as that in the Woolhope Valley in Herefordshire, and other places, together with those in N. Wales, we get the following as the typical series of the Upper Silurian rocks :—

		Feet.
	9. Tilestone	1000
Ludlow group .	8. Upper Ludlow rock	900
	7. Aymestry limestone	150
	6. Lower Ludlow rock	900
Wenlock group.	5. Wenlock limestone	150
	4. Wenlock shale	1400
	3. Woolhope limestone	50
Llandovery or May Hill group.	2. Tarannon shale	600
	1. Upper Llandovery rocks . . .	900

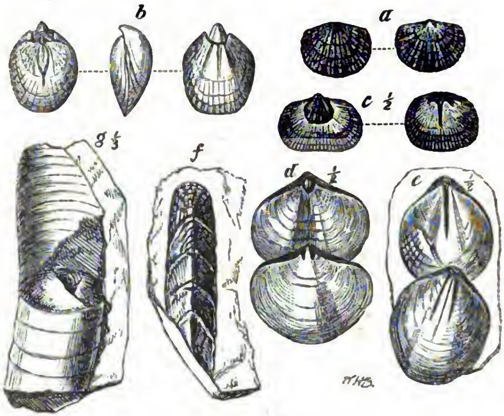
LLANDOVERY GROUP.—1. *The Upper Llandovery or May Hill Sandstone* is usually a gray, or brown, or yellow sandstone, sometimes becoming a conglomerate. The sandstones are sometimes calcareous, passing into courses of sandy limestone in some places.

The following is a list of the fossils which may be said to be characteristic of this group, taken from Salter and Morris's catalogue in the last edition of *Siluria.*

Actinozoa.	
Cyathophyllum angustum	Sil. foss., pl. 39.
Petraia bina (*and Wenlock*)	Sil. foss., pl. 38.
—— elongata	Sil. foss., pl. 38.
Brachiopoda.	
Atrypa hemisphærica	Foss. gr. 6, *a*.
Leptæna scissa	
Lingula crumena	Sil. foss., 12.
—— parallela	Mem. G. S. ii., pt. 1.*
Orthis lata	Sil. foss., pl. 9.
—— reversa	Foss. gr. 6, *c*.
Pentamerus globosus	Sil. foss., pl. 8.
—— lens	Foss. gr. 6 *d*.
—— oblongus	Foss. gr. 6 *e*.
—— undatus	Sil. foss., 14.
Rhynchonella angustifrons	Foss. gr. 6, *b*.
—— neglecta	Sil. foss., 9.
Strophomena arenacea (or concentrica).	
—— compressa	Sil. foss., 14.
Conchifera.	
Avicula bullata	M'Coy, Sil. foss.
Conocardium priste	M'Coy, Sil. foss.
Ctenodonta deltoidea	Mem. G. S. ii., p. 366.
—— Eastnori	Sil. foss., pl. 10.
—— lingualis	Mem. G. S. ii., p. 367.
Lyrodesma cuneatum	Mem. G. S. ii., p. 366.
Pterinæa sublævis	M'Coy, Sil. foss.
Gasteropoda.	
Chiton Griffithii	Foss. gr. 6, *f*.
Cyclonema quadristriatum	Mem. G. S. ii., p. 388.
Euomphalus prænuntius	*Ibid.*
Hollopella plana	M'Coy, Sil. foss.
—— tenuicincta	M'Coy, Pal. foss.

* Memoirs of the Geological Survey.

Macrocheilus fusiformis	Sil. foss., pl. 10.
Murchisonia augulata	*Ibid.*
Pleurotomaria fissicarina	Mem. G. S. ii., p. 357.
Raphistoma lenticularis	Sil. foss., pl. 10.
Trochonema tricinctum	M'Coy, Sil. foss., p. 14.
Trochus ? multitorquatus	*Ibid.*, p. 15.
—— tritorquatus	*Ibid.*, p. 12.



Fossil Group No. 6.
Llandovery Fossils.

a. Atrypa hemispherica.
b. Rhynchonella angustifrons.
c. Orthis reversa.
d. Pentamerus lens.
e. Pentamerus oblongus.
f. Chiton Griffithii.
g. Cyrtoceras approximatum.

Cephalopoda.

Cyrtoceras approximatum . . .	Foss. gr. 6 *g*.
Lituites undosus	Sil. foss., pl. 11.
Orthoceras Barrandii	Q. J. Geol. S., vii., p. 177.
Tretoceras bisiphonatum . . .	Sil. foss., pl. 11.

Echinodermata.

Palæaster coronella.	
Palæchinus ? Phillipsiæ . . .	M. G. S., ii., p. 584.
Pleurocystites Rugeri.	

Crustacea.

Acidaspis callipareos	Q. J. G. S., xiii., p. 308.
Phacops sublævis	M'Coy, Sil. foss., p. 51.

2. *The Tarannon shales* have already been sufficiently described at page 467. Although a distinct physical group of some importance in Wales, they seem to be confined to that country. Fossils are very rare in them, and it cannot therefore be said with certainty whether they belong most decidedly to the Llandovery group or to the Wenlock.

WENLOCK GROUP.—3. *Woolhope or Barr Limestone.*—A locally occurring group of beds of gray, argillaceous, nodular, concretionary limestone, interstratified with gray shales occasionally attaining a thickness of 100 feet.

It forms a ring round the dome of Llandovery sandstone in the Woolhope valley, and is well seen near Presteign, on the west flanks of the Malvern hills, at Great Barr in Staffordshire, and at May Hill.

4. *Wenlock Shale.*—Generally dark gray, sometimes black shale, with occasional calcareous concretions; 1400 feet thick.

5. *The Wenlock Limestone* is an irregularly occurring set of concretionary limestones, sometimes thin and flaggy, sometimes massive bosses of highly crystalline carbonate of lime; sometimes in one, sometimes in two or three sets of beds with interstratified shales, forming a thickness of 100 to 300 feet.

These beds are admirably shewn in all the country between Aymestry and Ludlow, and along Wenlock Edge to Benthal Edge near Coalbrookdale, as well as at the places just mentioned as showing Woolhope Limestone, and at the Castle Hill and Wrens Nest near Dudley; as also near the town of Walsall in Staffordshire, and in the neighbourhood of Usk in Monmouthshire.

Characteristic Fossils.—In all these places the beds, especially the limestones, abound in fossils, of which the following list is a selection that includes the most abundant and characteristic species. Many of the species, however, which abound in the greatest profusion in the Wenlock rocks, are to be found, though rarely, in either earlier or later formations, or in both. These, then, are not characteristic in the sense of being peculiar to the Wenlock rocks, but as being more abundant in them than elsewhere. Here, too, as in some other parts of the geological series, it is the assemblage of fossils that becomes characteristic; any one or two of these species may be found in some other groups, but in no other are they all assembled together in the abundance in which they occur in the Wenlock rocks.

Spongidæ.

Stromatopora striatella	Sil. foss. 51.

Actinozoa.

Acervularia ananas	Foss. gr. 7, *a*.
Alveolites repens and Labechei . .	Sil. foss. 17.
Favosites Gothlandica . . .	Sil. foss. 17.
Heliolites Grayi.	
Omphyma turbinatum . . .	Foss. gr. 7, *b*.
Petraia bina	Sil. foss. 52, pl. 38.
Syringopora bifurcata . . .	Sil. foss. 19.
Stenopora filrosa (*from Llandeilo to Ludlow*)	Sil. foss. 17.

Polyzoa.

Cellepora favosa.	
Ceriopora affinis.	
Discopora antiqua	Sil. foss., pl. 41.
Fenestrella Lonsdalei	*Ibid.*
? Graptolithus Flemingii. . . .	Q. J. G. S., viii., p. 390.
Ptilodictya scalpellum . . .	Sil. foss. 50.

Brachiopoda.

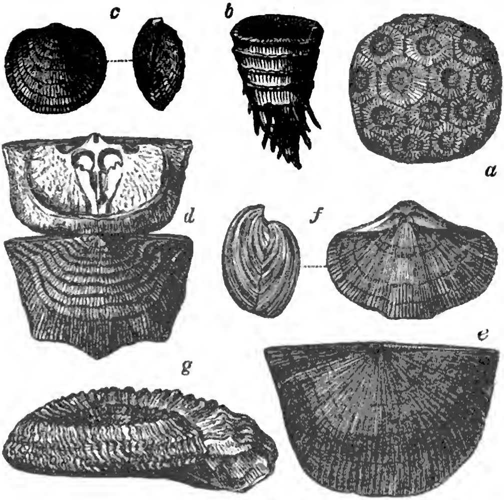
Atrypa reticularis (*Llandovery to Ludlow*)	Foss. gr. 7, *c*.
Discina Forbesii	Sil. foss. 57.
Obolus transversus.	
Orthis elegantula (*from Bala to Ludlow*)	Sil. foss., pl. 5.
—— rustica.	
Pentamerus galeatus (*and Ludlow*) .	Sil. foss., pl. 21.
Retzia Bailyi	Sil. foss. 57.
Rhynchonella navicula (*and Ludlow*) .	Sil. foss., pl. 22.
—— Wilsoni (*Llandovery to Ludlow*) .	*Ibid.*
Siphonotreta Anglica	Sil. foss. 57.
Spirifera plicatella (*Llandovery to Ludlow*)	Foss. gr. 7, *f*.
Strophomena depressa (*Bala to Ludlow*)	Foss. gr. 7, *d*.
—— euglypha (*Llandovery to Ludlow*)	*Ibid.*, 7, *e*.

Conchifera.

Cardiola fibrosa (*and Ludlow*) . .	Sil. foss., pl. 23.
Conocardium (Pleurorhyncus) equicostatum	Sil. foss. 59.
Modiolopsis antiqua	*Ibid.*
Mytilus Chemungensis . . .	Mem. G. S. ii., p. 365.
Pterinæa retroflexa (*Llandovery to Ludlow*)	Foss. gr. 9, *e*.

Gasteropoda.

Acroculia haliotis	Sil. foss., pl. 24.
Chiton Grayanus.	
Euomphalus discors	Foss. gr. 7, *g*.
—— funatus	Sil. foss., pl. 25.
—— rugosus	*Ibid.*, 24.
Murchisonia Lloydii (*and Ludlow*) .	*Ibid.*



Fossil Group No. 7.
Wenlock Fossils.

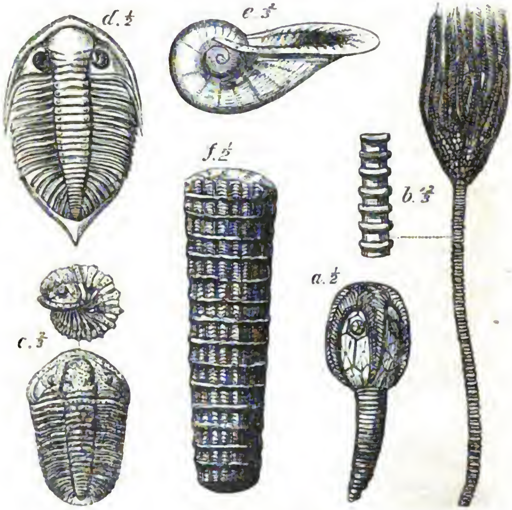
a. Acervularia ananas.
b. Omphyma turbinatum.
c. Atrypa reticularis.
d. Strophomena depressa.
e. Strophomena euglypha.
f. Spirifera plicatella.
g. Euomphalus discors.

Heteropoda and Pteropoda.

Bellerophon dilatatus (*and Bala*) . .	Foss. gr. 8, *e*.
—— Wenlockensis	Sil. foss., pl. 25.
Conularia Sowerbyi (*and Bala*) . .	*Ibid.*
Theca anceps	Mem. G. S. ii., p. 355.

Cephalopoda.

Lituites Biddulphii	Sil. foss., pl. 31.
Orthoceras annulatum (*and Bala*) . .	Foss. gr. 8, *f.*
—— Maclareni	Sil. foss. 24.
—— ventricosum	Q. J. Geol. Soc. ii.



Fossil Group No. 8.

Wenlock Fossils.

a. Pseudocrinites quadrifasciatus.
b. Periechocrinus moniliformis.
c. Calymene Blumenbachii.
d. Phacops caudatus.
e. Bellerophon dilatatus.
f. Orthoceras annulatum.

Echinodermata.

Actinocrinus pulcher	Pal. foss., p. 1.
Crotalocrinus rugosus	Sil. foss. 55.
Cyathocrinus goniodactylus . . .	*Ibid.*, pl. 14.
Echino-encrinites armatus . . .	*Ibid.*, 54.
Eucalyptocrinus decorus . . .	*Ibid.*, pl. 14.
Marsupiocrinus cælatus	*Ibid.*, 55.

Periechocrinus moniliformis . .	Foss. gr. 8, *b*.
Pseudocrinites quadrifasciatus . .	*Ibid.*, *a*.
Taxocrinus tessaracontadactylus . .	Sil. foss., pl. 14.

Annelida.

Cornulites serpularius	Sil. foss., pl. 16.
Serpulites longissimus (*and Ludlow*) .	*Ibid.*
Tentaculites ornatus	*Ibid.*

Crustacea.

Acidaspis Barrandii	Sil. foss. 64.
Ampyx parvulus	Mem. G. S., p. 350.
Beyrichia Klœdeni (*from Llandovery to Tilestone*)	Sil. foss. 63.
Calymene Blumenbachii (*from Bala to Ludlow*)	Foss. gr. 8, *c*.
Cyphaspis pygmæus	Dec. G. S. 7.
Encrinurus variolaris	Sil. foss. 64.
Homalonotus delphinocephalus . .	*Ibid.*, 16.
Illænus Barrensis	Dec. G. S. ii.
Lichas Anglicus	Sil. foss. 63.
Phacops caudatus (*Llandovery to Ludlow*)	Foss. gr. 8, *d*.
Proetus latifrons	Sil. foss. 64.
Sphærexochus mirus (*and Bala*) . .	*Ibid.*
Staurocephalus Murchisoniæ (*and Bala*)	*Ibid.*, 10.

Ludlow Group.—6. *The Lower Ludlow rock* of Shropshire, is at its base not unlike the Wenlock shale—a dark sandy shale, with spheroidal calcareous concretions, becoming more sandy and flaggy above, generally of a pale grayish or greenish brown colour. It is usually soft, and easily decomposing, so as to receive the local name of mudstone. The shales are often capped by beds of impure fuller's earth (provincially called Walker's earth, apparently a corruption of the German "walkerde"), which support the Aymestry limestone.

7. *The Aymestry Limestone* is a dark gray limestone, rarely so thick or so pure as the Wenlock limestone often is. In South Staffordshire the workmen call the Wenlock "the white limestone," and the Aymestry "the black limestone." It is generally evenly bedded and flag-like, being usually earthy or argillaceous, with small concretions. It often dies away into a mere band of calcareous nodules.

8. *The Upper Ludlow rock* greatly resembles the lower, being a slightly micaceous sandy shale or flag, or soft argillaceous sandstone (mudstone), generally thin bedded, of bluish gray colour within,

weathering externally to a rusty brown or greenish gray. Large spheroidal concretions occur in it. The upper part of these beds passes by insensible gradations into red sandy flags, locally called tile stones.

9. *The Tilestone.*—In Shropshire the gradation from the grayish or greenish Upper Ludlow rocks into the overlying red beds is rather a rapid one. There occur, just near the junction, one or two little bands, called bone beds, consisting of the agglutinated fragments of fish and crustacea, which may be assigned to one or other group. The Downton Castle building stone, a light coloured, thin bedded, slightly micaceous sandstone, lies above these bone beds.

In South Wales, about Llandovery and Llandeilo, the Upper Silurian rocks lose all their distinctive limestones, and can only be treated as one group of Upper Silurian, distinct from the Lower Silurian below. They are usually vertical, and as we pass across their edges we find the upper beds alternating with red beds, and gradually passing into a mass of red rocks above—fossils occurring wherever the beds happen not to be red.

On the banks of the river Sawdde, near Llangaddock, is a section which I have observed myself, and which has been described by Sir H. Delabeche in the Memoirs of the Geological Survey. The following is an abstract of its upper part:—

	Feet.
5. Gray micaceous, laminated sandstone, *fossiliferous*	390
4. Red sandstones, marls and conglomerates . .	700
3. Purplish gray micaceous sandstones, etc., *fossiliferous*	370
2. Band of red conglomerate.	
1. Gray and brown sandstones, flagstones, and shales often very *fossiliferous*	2000

Below No. 1 we come down into Lower Silurian beds, while above No. 5 the beds are all red, and, so far as is known, quite unfossiliferous. The fossils in all the beds from 1 to 5 are Upper Silurian fossils, and the top of the group 5 is taken in the maps of the Geological Survey as the boundary of the Upper Silurian, all above being considered to be Old Red Sandstone.

If we take groups 2 to 5 as Tilestones, we shall get a thickness of nearly 1500 feet for that sub-division. (See Mem. G. S., p. 23, and sheet 41 of the Geol. Sur. Map.)

Characteristic Fossils.—The following is a select list of the fossils most characteristic of the Ludlow group:—

Actinozoa.

Cyathaxonia Siluriensis	M'Coy, Pal. foss., p. 36.

Polyzoa.

Graptolithus priodon	Foss. gr. 9, *a.*

Brachiopoda.

Discina rugata	Sil. foss., pl. 20.
—— striata	*Ibid.*
Lingula cornea	Sil. foss. 22.
—— lata	Sil. foss., pl. 20.
—— striata	*Ibid.*
Orthis lunata	Foss. gr. 9, *b.*
Pentamerus Knightii	*Ibid., c.*
Rhynchonella nucula (*from Llandovery to Ludlow*)	*Ibid., d.*
—— pentagona	Sil. foss., pl. 22.

Conchifera.

Avicula Danbyi	Foss. gr. 9, *f.*
Anodontopsis (several species) . .	M'Coy, Sil. foss., p. 23.
Ctenodonta Anglica	Sil. foss., pl. 23.
Cucullela Cawdori	Sil. foss., pl. 34.
Goniophora cymbæformis . . .	*Ibid.*, pl. 23.
Modiolopsis complanata . . .	*Ibid.*
Orthonota (several species of M'Coy's).	
Pterinæa retroflexa (*and Wenlock*) .	Foss. gr. 9, *e.*

Gasteropoda.

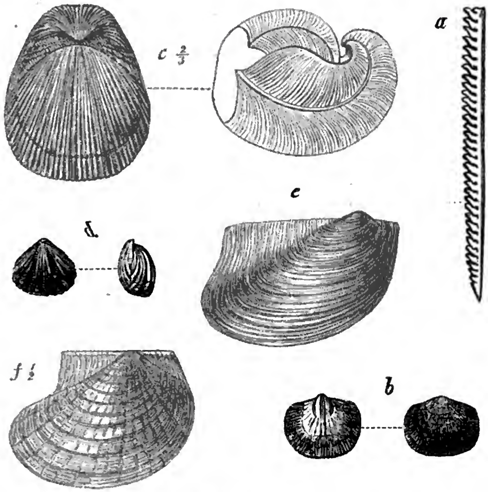
Acroculia euomphaloides	M'Coy, Sil. foss., p. 290.
Cyclonema corallii	Foss. gr. 10, *a.*
Euomphalus carinatus	Sil. foss., pl. 24.
Holopella cancellata	Sil. foss. 14.
Loxonema sinuosum	Sil. foss., pl. 24.
Murchisonia articulata	*Ibid.*
Natica parva	*Ibid.*, 25.
Pleurotomaria undata	*Ibid.*, 24.

Heteropoda and Pteropoda.

Bellerophon expansus	Foss. gr. 10, *d.*
Conularia subtilis.	
Ecculiomphalus lævis	Sil. foss., pl. 25.
Theca Forbesii (*and Wenlock*) . .	Q. J. Geol. Soc. ii., p. 314.

Cephalopoda.

Ascoceras Barrandii	Sil. foss. 62.
Lituites articulatus	Sil. foss., pl. 31.
Orthoceras bullatum	Foss. gr. 10, *e*.
Phragmoceras ventricosum (and other species)	*Ibid.*, *f*.



Fossil Group No. 9.

Ludlow fossils.

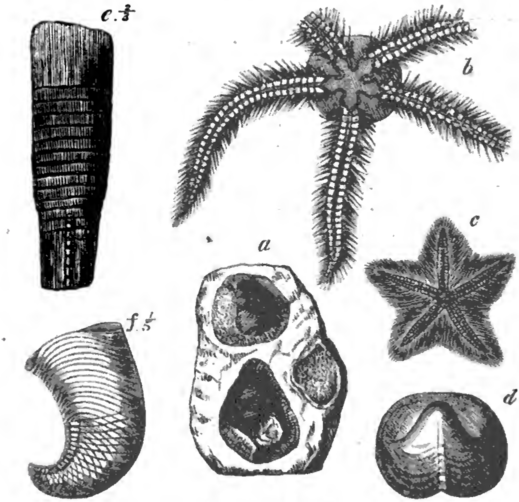
a. Graptolithus priodon.
b. Orthis lunata.
c. Pentamerus Knightii.
d. Rhynchonella nucula.
e. Pterinea retroflexa.
f. Avicula Danbyi.

Echinodermata.

Palæaster Ruthveni (and other species) .	Sil. foss. 56.
Palæochoma Colvini (and three other species)	Foss. gr. 10, *c*.
Protaster Miltoni (and other species) .	*Ibid.*, *b*.
Taxocrinus Orbignyi	M'Coy, Pal. foss., p. 53.

Annelida.

Crossopodia lata	M'Coy, Pal. foss., p. 130.
Serpulites dispar	*Ibid.*, Ap., p. 1.
Tentaculites tenuis	Sil. foss., pl. 16.
Trachyderma coriaceum and squamosum	Mem. G. S. ii., p. 331.



Fossil Group No. 10.
Ludlow fossils.

a. Cyclonema corallii.
b. Protaster Miltoni.
c. Palæochoma Colvini.
d. Bellerophon expansus.
e. Orthoceras bullatum.
f. Phragmoceras ventricosum.

Crustacea.

Acidaspis coronata	Q. J. Geol. Soc. xiii., p. 210.
Calymene Blumenbachii	Foss. gr. 8, *c.*
Ceratiocaris Murchisonii (and four other species)	Sil. foss., pl. 19.
Encrinurus punctatus (*from Llandovery to Ludlow*)	Sil. foss. 14.
Eurypterus abbreviatus (and five other species)	Q. J. Geol. Soc., vol. xv.

Homalonotus Knightii . . .	Sil. foss., pl. 19.
Lichas anglicus (*and Wenlock*) . .	Sil. foss. 63.
Phacops caudatus, Downingiæ, and longicaudatus (*and Wenlock*) . . .	Sil. foss., pl. 17.
Proetus latifrons (*Llandovery to Ludlow*).	Sil. foss. 64.
Pterygotus acuminatus . . .	Sil. foss. 25.
—— problematicus (and several other species)	Dec. G. S. 10.

Fish.

Onchus Murchisonii (and other species)	Sil. foss., pl. 34.
Plectrodus mirabilis	*Ibid.*, 35.
—— pustuliferus	*Ibid.*, 35.
Pteraspis Banksii	Sil. foss. 65.
—— truncatus	*Ibid.*
Sphagodus	Sil. foss., pl. 35.

Characteristic Fossils of the Tilestones.—The following are the fossils which are stated in Salter and Morris's list to have been found in what are there styled "passage beds," which Sir Roderick Murchison refers to the thin beds above the Downton Castle stone exhibiting a passage from the Upper Ludlow to the Old Red Sandstone (so called) :—

Brachiopoda.

Lingula cornea (*from the Ludlow*) .	Sil. foss. 22, pl. 34.

Gasteropoda.

Platyschisma helicites (*from the Ludlow*)	Sil. foss. 25, pl. 34.

Crustacea.

Beyrichia Klœdeni (*from the Llandovery*)	Sil. foss. 63.
Eurypterus acuminatus (*peculiar*) .	Q. J. G. S., xv.
—— linearis (*from the Ludlow*) . .	*Ibid.*
—— megalops (*peculiar*) . . .	*Ibid.*
—— pygmæus (*from the Ludlow*) .	Sil. foss. 66.
Leperditia marginata (*do.*)	
Pterygotus anglicus (*peculiar*) . .	Sil. foss. 21.
—— Ludensis (*do.*)	De. G. S. 10.
—— gigas ? (*from the Ludlow*) . .	*Ibid.*
Parka decipiens, eggs of Pterygotus (*peculiar*).	

Fish.

Auchenaspis Salteri	Sil. foss. 21:
—— ? (Cephalaspis) ornatus . .	*Ibid.*

Cephalaspis Murchisonii (and another species)	Sil. foss. 22.
Onchus Murchisonii (*from the Ludlow*).	Sil. pl. 35.
? Plectrodus mirabilis (*do.*)	*Ibid.*
? Pteraspis Banksii (*do.*)	Sil. foss. 67.

The description of the Upper Silurian rocks just given, applies to them throughout Shropshire and Staffordshire, Herefordshire and Worcestershire, Monmouthshire and Gloucestershire. If we proceed from that district into either North Wales or South Wales, a great change takes place in them, since all the limestones die out and disappear, and the clays and shales pass into hard slates and flags, while coarse sandstones and fine hard grits make their appearance among them.

It is barely possible to separate the Upper Silurian into two groups—the Ludlow and the Wenlock—in the Clun Forest district, and thence through Radnor Forest down to Llandeilo towards the south, or in the Long Mountain (between the Stiperstones and the Breiddens) on the north.* In all those places they pass conformably and gradually up into the overlying red series (Tilestones or Passage beds) which have hitherto been considered the base of the Old Red Sandstone.

Farther north, in Denbighshire, even this separation has been found impracticable. The Upper Silurian consists of the Tarannon shales, probably representing the Llandovery beds, and the Denbighshire sandstones, which represent the lower part of the Wenlock shale, and pass up into a great series of dark flags and slates, which represent the upper part of the Wenlock group, and possibly more or less of the Ludlow series. These beds are very highly inclined and greatly

* In sheet 30 of the Horizontal Sections of the Geological Survey, which crosses Clun Forest, we have the following series described by Mr. Aveline:—

		Feet.
Supposed Old Red Sandstone.	Red marl and fissile gray micaceous sandstone (used for tiles) with thicker beds of light coloured sandstone	1500
Ludlow Group.	Sandy, flaggy, brown shales, and dark brown sandstone, upper beds very fossiliferous, lower quarried for flagstone	6000
Wenlock Group.	Grayish brown and blue sandy argillaceous shale, passing down into thick, gray, gritty sandstones with bands of dark slate (Denbighshire sandstones)	5000

In sheet 4, which runs over Mynnydd bwlch-y groes, near Llandovery, the section crosses the edges of the following beds, all vertical:—

		Feet.
Red beds of supposed Old Red Sandstone.		
Tilestones.—Laminated, gray, micaceous sandstone, fossiliferous		800
Ludlow and Wenlock.	Sandstones, thick above, thinner below, having gray shales and calcareous bands interstratified, with most shales near the base .	5500
Llandovery.	Pale blue, green, and brown shales (Tarannon)	600
	Thick beds of coarse sandstone, with layers of Pentameri . .	300

denuded, and small patches of Old Red Sandstone lie here and there, nearly horizontally, across their often vertical edges, the Silurians striking east and west, while the Old Red ranges from south to north.

These Denbighshire flags contain an abundance of large Theca, or other Pteropodous shells (called at one time Creseis, by E. Forbes, Geol. Jour., vol. i., p. 146, and ii., p. 314), as well as groups of Crinoids in some places, and other fossils (Cardiola interrupta, etc.), which prove their Upper Silurian character independently of their lying above the Bala beds of the Berwyns, and Cyrn y Brain, and those of Merioneth and Caernarvon.—(See Maps, sheets 71 and 74, and sections, sheets 38 and 39, of the Geological Survey.)

Cumberland, etc.—According to Professor Sedgwick the following are the typical groups of rocks deposited during the Upper Silurian period in the north of England :—

3. Kendal group = Ludlow rocks.
2. Ireleth slates = Wenlock rocks.
1. Coniston grits = May Hill sandstone.

1. The Coniston grits have few fossils, and their identity with the May Hill sandstone is therefore doubtful, although very probable.

2. The Ireleth slate group is divided into four stages :—*a*, Lower Ireleth slate ; *b*, Ireleth limestone ; *c*, Upper Ireleth slate ; *d*, Coarse slate and grit. Fossils are rare, but generally of the Wenlock type.

3. The Kendal group is divided into three stages : *a*, A great group of flags and grits ; fossils abundant and of the Lower Ludlow type. *b*, Thick grit and flagstone, with bands of coarse slate ; fossils locally abundant, and of Upper Ludlow type ; *c*, Tilestones, resembling those of Shropshire, etc.—(Sedgwick, *Synopsis of Classification, etc.*)

Four species of star-fish have been found by Professor Sedgwick in the Kendal group (stage *b*), of which Uraster primævus is the most abundant, and Protaster Sedgwickii the most interesting, as being the only known fossil representative of the Euryalidæ (Mem. Geol. Soc., Dec. 1).

Scotland.—Representatives of the Llandovery rocks appear to occur near the coast of the southern part of Ayrshire, in Saugh Hill, south of Girvan (*Siluria*, 3d edition, chap. viii.), resting on the Lower Silurian rocks of the northern flank of the border Highlands, while rocks, believed to be of Wenlock age, repose on their southern flank in the headlands of Kirkcudbright Bay.

The Pentland Hills are also supposed by Sir R. I. Murchison (*ib.*) to contain rocks of Wenlock age ; and to the west-south-west of them, near Lesmahago, five miles south-west of the town of Lanark, are groups answering to the Ludlow and Tilestone (or passage) beds, previously spoken of.—(*Siluria*, chap. viii., p. 175.)

Here there has been exposed by denudation of the Lower Old Red Sandstone (so-called), a considerable thickness of green, gray, and dark shales and flags, passing up quite conformably and by insensible gradations into several thousand feet of red shales, sandstones, and conglomerates. That the Silurian beds are the representative of the Ludlow group, is proved by the fossils found by Mr. Slimon, of Lesmahago, consisting of large Pterygoti, Ceratiocaris, Lingula cornea, and other fossils, such as occur in the Ludlow and Tilestone beds of Hereford and Salop. Some of the Pterygoti are believed to have exceeded six feet in length.

Ireland.—Representatives of the Llandovery beds are to be found largely in Galway, about Maam, and the south-west end of Lough Mask, some of the upper beds being probably of Wenlock age. This is the case with the beds of Ughool, near Ballaghadereen, and possibly with those of Lisbellaw, south of Enniskillen. In all these places great conglomerates abound, containing rounded blocks of syenite of one or two feet in diameter.

Beds, probably of Llandovery age, are to be found also in the Cratloe Hills of Limerick, on the west flank of Cahirconree in Kerry, and probably also in the Anascaul Valley, on the south side of the Dingle Promontory.

At the extremity of that promontory, between Ferriters Cove and Dunquin, and thence to Smerwick Harbour, certain beds occur which appear to represent both the Wenlock and Ludlow groups, since crowds of fossils, characteristic of those beds, are to be found there. A certain line has been drawn by Mr. Du Noyer, beneath which Wenlock species abound, while above it are many Ludlow species, including, in some places, many specimens of Pentamerus Knightii, the species being identified by Mr. Salter on the ground.

These beds are, however, greatly disturbed and confused, and bent into violent contortions, if not inverted. Certain beds of purple, and green, and yellow sandstones, etc., lie apparently beneath the Wenlock beds, and graduate up into them, peculiar conglomerates occurring both in the fossiliferous beds and in the beds below them. These are called by the Geological Survey by the provisional name of the Smerwick beds.

Over the Ludlow beds, again, there sets in a vast thickness of green and purplish grits, interstratified with red shales, and having in the upper beds purple conglomerates, with pebbles containing Llandovery fossils. These we call the Dingle beds. They appear to occupy the same position as the red beds above the Ludlow rocks in Shropshire and Herefordshire, in South Wales, and in Scotland, but no fossils have yet been found in them in Ireland. They will be mentioned again in the next chapter.

Bohemia.—The rocks deposited during the Upper Silurian Period

in what is now Bohemia, are divided by M. Barrande into—Stage E, Calcaire inferieur. Stage F, Calcaire moyen. Stage G, Calcaire superieur. Stage H, Schists culminans.

Scandinavia.—M. Angelin similarly divides the Upper Silurian rocks of this district into his Regio D E, Harparum, shales and white limestones, and Regio E, Cryptonomorum, limestones resting on sandstones and shales.

Of these, Stage E of Barrande and Regio E of M. Angelin certainly equal very nearly the Wenlock rocks of Sir R. I. Murchison, there being 18 species of Brachiopods, besides corals and other fossils, common to this group of rocks in the three countries. Sir R. I. Murchison gave, in 1847, a list of 74 species found in the rocks of Gothland (Regio E), 47 of which occur in Britain, 13 in Ludlow rocks, and 14 in the Wenlock, the 20 others being found in both. The Regio D E, of M. Angelin, is not represented in Bohemia. It may possibly be equal to the Llandovery or May Hill sandstone. The stages F, G, H, of Barrande are not recognisable in Scandinavia. There are 167 species of trilobites in the Upper Silurians of Bohemia, and 99 in those of Scandinavia, with only *one* species, the Calymene Blumenbachii, common to the two countries. The total thickness of the Upper and Lower Silurian and Cambrian rocks of Bohemia is between 30,000 and 40,000 feet; that of the same rocks in Scandinavia is not more than 1000 or 1200 feet. Of the total number of fossil species found in the two countries (which is from 2000 to 2500), not more than one per cent are common to the two countries, except in the Brachiopods, in which the number may perhaps rise to five per cent.—(See M. Barrande's very interesting *Parallèle entre les depôts Siluriens de Boheme et de Scandinavie*, Prague, 1856.) M. Angelin says that in Scandinavia there is not one species common to any two of his seven Regiones; but this may perhaps arise from his over minute distinctions in the species of Mollusca, etc. M. Barrande has, however, only a few species common to any two of his six stages. If, on the other hand, we look at the number of *genera* of trilobites in Scandinavia and Bohemia, we find 39 in Bohemia and 45 in Scandinavia, of which 30 are common to the two countries, those 30 being the most important and well-established genera, containing the greatest number of species and individuals.

North America.—The rocks of this region of the age of the Upper Silurian period, are—

		Feet.
LOWER HELDERBERG GROUP.	10. Upper Pentamerus limestone .	300
	9. Encrinal limestone . . .	
	8. Delthyris shaly limestone . .	
	7. Lower Pentamerus limestone .	
	6. Tentaculite limestone . . .	

		Feet.
ONONDAGA AND NIAGARA GROUP.	5. Onondaga salt group, a gray ash-coloured shale, with gypsum and rock-salt 4. Niagara limestone, compact gray limestone, resting on blue calcareous shale	1000
CLINTON GROUP.	3. Clinton rocks. *c.* Variegated red marls and calcareous shales . . . . . *b.* Shales and argillaceous limestone and calcareous sandstone . *a.* Greenish and yellowish slates with ferruginous sandstone .	2400
MEDINA GROUP.	2. Medina sandstone. *b.* White fine-grained sandstone, alternating with red and greenish shale at top	450
	a. Soft brown argillaceous sandstone, and red shale	600
	1. Gray sandstone with thick beds of siliceous conglomerate (Oneida), containing fragments of the lower rocks .	400

According to Professor Rogers (Johnston's Physical Atlas, 2d edition), not only does the Medina group contain a conglomerate (Oneida) made of pebbles of the lower rock, but it and the whole Upper Silurian rocks are distinctly unconformable to the Lower, as they are in Wales and other parts of the world.

Characteristic Fossils.—The Clinton group contains Pentamerus oblongus and lævis; and together with the Medina group is probably the representative of the Llandovery rocks or May Hill sandstone. The Niagara limestone contains Calymene Blumenbachii; Homalonotus delphinocephalus; Rhynchonella Wilsoni and cuneata; Orthis elegantula; Pentamerus galeatus; Orthoceras annulatum; Favosites gothlandica, etc.; and is therefore of nearly the same age as the Wenlock series.—(*Lyell's Manual.*)

Professor Ramsay, in his table (*Siluria*, p. 472), looks upon the Lower Helderberg group as equivalent to the Lower Ludlow, and says that one of the Pentameri (P. occidentalis) is like P. Knightii, but smaller. Eurypterus also occurs in the upper beds.

It does not appear that there is any exact equivalent of the Upper Ludlow rocks, and there appears to be a break between the top of the Lower Helderberg group and the next formation, as the Oriskany

sandstone rests in denuded hollows of it.—(See also Dr. Bigsby's paper before mentioned.)

In the Geological Reports of Canada for the year 1856, Mr. Richardson describes the structure of the Island of Anticosti, and Mr. Billings the fossils collected. From these descriptions it appears that there is a series of beds resting quite unconformably on the Laurentian gneiss, and dipping at a very gentle angle across the island from north to south. This series is 4500 feet thick, consisting of several great groups of limestones, interstratified with shales and slates. It is divided into six groups, the lower three of which, with a thickness of about 1300 feet, answer to the Lower Silurian Black River and Hudson groups. But there then come in, in the upper three groups, abundance of Pentameri (P. lens among them), and other fossils answering to those of the Medina and Clinton groups, so that there is believed to be a regular gradation here from the Lower Silurian into the Upper Silurian formations.

As all geological boundaries are based upon the absence of beds, which may elsewhere exist, we must always expect to find our arbitrary boundaries becoming evanescent with advancing knowledge.

Life of the Period.

In the discussion of the forms of life existing during the two preceding periods, we seemed, and perhaps only seemed, to be treating of the very commencement of life upon the globe. The only question of the kind still to be asked is as to the commencement of vertebrate life. During the latter part of the present period, however, we know that fish existed, and that therefore all the five sub-kingdoms into which animal life is now divisible, the Protozoa, the Cœlenterata, the Mollusca, the Annulosa, and the Vertebrata, were in existence, and have remained so ever since this third known period of the world's history.

If we examine the list of fossils, drawn up by Salter and Morris for the 3d edition of Sir R. I. Murchison's *Siluria*, and if, as is there done, we club together the Lower and Upper Llandovery rocks into one group, we find that out of 947 separate species, there are twenty-one which are common to the Lower Silurian groups and the Llandovery rocks, but are not found in any higher beds. Of these one only, viz., Orthis Actoniæ, proceeds from the Llandeilo group, the rest being all Bala species.

If we omit the Llandovery rocks, we find fifty-one other species, or about $5\frac{1}{2}$ per cent of the whole series of fossils, which are found both in beds below and beds above the Landovery rocks. Three of these, namely, Stenopora fibrosa, Orthis elegantula, and Cucullela anglica, are said to range from Llandeilo into Ludlow rocks, and three from

Llandeilo to Wenlock, namely, Halysites catenularius, and Orthis biforata and calligramma. Of the other forty-five, fifteen range from Bala to Ludlow rocks, and thirty from Bala to Wenlock only. However subsequent discoveries may alter the absolute numbers here given, it is probable that their proportions will remain much the same.

The few species which ranged from the Llandeilo flags into the Wenlock or Ludlow groups, resembled the few which, having lived at an early tertiary period, still survive among ourselves after the gradual extinction of such multitudes of their contemporaries. They belong, moreover, to comparatively low orders of life, which are apt to be of much longer existence than the higher classes.

Only five trilobites, namely, Acidaspis Brightii, Calymene Blumenbachii, Cheirurus bimucronatus, Cyphaspis megalops, and Lichas Grayii, extend from the Bala beds into the Wenlock or Ludlow rocks.

Of the Graptolites, which seem not to have come into existence till after the deposition of the Lingula flags, and the extinction of Barrande's so-called Primordial fauna, all those which may be called double and twin Graptolites died out at the close of the Lower Silurian period; and of the single Graptolites, one only, Graptolithus priodon (called by some Graptolithus Ludensis), survived from the time when the Bala beds were deposited, to that when the Ludlow rocks were formed. One other species of Graptolite, called Graptolithus Flemingii, has also been found in the Kirkcudbright beds, which are believed to be of the age of the Wenlock shale.

No other Graptolites have been found in Upper Silurian rocks in the British islands, nor in any newer rock in any part of the world.

New Genera.—The following generic forms first (so far as is yet known) came into existence within the British area during this period, those with an asterisk not surviving it:—

Actinozoa, Acervularia, Alveolites, * Aulacophyllum, Chætetes, * Cladocora, Chonophyllum, Clisiophyllum, * Cœnites, Cyathaxonia, Cyathophyllum, Cystiphyllum, Fistulipora, * Goniophyllum, * Labechia, Lonsdaleia, * Palæocyclus, Ptychophyllum, * Thecia, Zaphrentis.

Polyzoa, Cellepora, Ceriopora, Discopora, ? Escharina, Fenestrella, Glauconome, ? Heteropora, * Nidulites, Polypora, ? Retepora, * Retiolites.

Brachiopoda, Athyris, Chonetes, Pentamerus, * Porambonites, Retzia, ? Terebratula.

Conchifera, Anodontopsis, Avicula, * Clidophorus, Dolabra, Goniophora, * Grammysia.

Gasteropoda, * Acroculia, Chiton, Loxonema, Natica, Platyschisma, ? Trochus, Turbo.

Cephalopoda, * Ascoceras, * Nothoceras, * Phragmoceras, * Tretoceras.

Echinodermata, Actinocrinus, *Apiocystites, * Cheirocrinus, * Crotalocrinus, Cyathocrinus, * Dimerocrinus, *Echinoencrinites, * Enallocrinus, *Eucalyptocrinus, *Ichthyocrinus, *Ischadites, *Lepidaster, * Macrostylocrinus, * Marsupiocrinus, Palæchinus, * Palæocoma, * Palæodiscus, * Palasterina, * Periechocrinus, * Pisocrinus, Platycrinus, Pleurocystites, * Prunocystites, * Pseudocrinites, * Rhopalocoma, Taxocrinus, * Tetragonis, * Tetramerocrinus.

Annelida, * Cornulites, Spirorbis.

Crustacea, * Ceratiocaris, * Deiphon, Eurypterus, * Proetus, Pterygotus, Parka (eggs of Pt.)

Fish, Auchenaspis, Cephalaspis, Onchus, *Plectrodus, Pteraspis, Sphagodus.

In this list we may remark a considerable addition to the genera of Corals, while the new genera of Brachiopods are few ; one shell being referred to Terebratula, to which many living Brachiopods belong. Some new genera of ordinary bivalves appear, among whieh Avicula still survives. Of the Gasteropods, the genus Chiton now began to exist, and has been represented by a few successive species down to our own day, when they are very numerous. Shells, scarcely to be distinguished from the existing genera Turbo and Trochus, but which may, perhaps, have been oceanic like Ianthina, also existed.

Some peculiar modifications of the strange Orthoceras family also made their appearance during this period, and became extinct probably at its close.

Among the Echinodermata we have numerous peculiar genera of Crinoidea (or sea-lilies) and some others that were still more developed during the Carboniferous period. The remarkable extinct family of Cystidea also shewed several peculiar genera, and then the whole family died out. Several kinds of star-fish have been found beautifully preserved in some of the rocks of the period, and are only to be distinguished from existing star-fishes by Echinodermatists, who study the arrangement of the little plates and other minuter characters of the class.

In the Crustacean class we find the Phyllopod (or shrimp-like) Ceratiocaris, continuing the order which commenced with Hymenocaris in the Lingula flags ; but two new genera of Trilobites appear while the larger and more lobster-like Eurypteridæ shew two genera, Eurypterus and Pterygotus, which become larger and more numerous in the next period.

The Fish of the genus Pteraspis and its allies were probably Ganoid fish, or covered with enamelled bony scales, like the bony pike (Esox osseus) of the North American lakes ; while Onchus or Sphagodus seem to have had a *shagreen* covering like that of the sharks of our times.

Palæozoic Corals.—It may be well, perhaps, to seize this oppor-

tunity of the first appearance of large corals to say a few words on Palæozoic corals in general, taking as a guide Professor Greene's lately published Manual of the Cœlenterata. He divides the sub-kingdom Cœlenterata into two classes—Hydrozoa and Actinozoa. The Hydrozoa include the Hydra or fresh-water polyps, the Sertularidæ, the Vellelæ, the Medusæ, and others, mostly soft-bodied animals, incapable of preservation as fossils, except those which, like Sertularia and Campanula, etc., are often called "sea-weeds."

The Actinozoa are either soft or coral-forming, and are divided into four orders — 1, Zoantharia; 2, Alcyonaria; 3, Rugosa; 4, Ctenophora.

To Zoantharia belong the soft Actiniæ, and almost all living Corals.

To Alcyonaria belong the Alcyonium or Deadman's fingers, the Tubipores or organ-pipe corals, the Pennatulæ or sea-pens, and the Gorgonias or sea-fans, to which Corallum (giving the red coral) belongs.

The Rugosa are an entirely extinct order, being, with one exception, confined to Palæozoic rocks, and are only known by their corals.

The Ctenophora have no hard parts; they include many beautiful Oceanic creatures, such as Beroe, Venus's girdle, etc., and are often brilliantly phosphorescent. They, of course, are not known as fossils.

The external tentacles and internal mesenteries, or walls of the body compartments, of the Zoantharia, are either five or six, or multiples of five or six, and the vertical plates or septa of the internal cavities of the corals of those Zoantharia which secrete corals, follow the same numerical law.

In the Rugosa, however, these internal plates or septa are either four or multiples of four, and they are therefore separated as a distinct order from the other coral-forming Actinozoa, since in the numerical law of division of their parts, they agree with the Alcyonaria, which have always eight tentacles, and the internal chambers of which are always some multiple of four.

The order Zoantharia is divided into three sub-orders, the first of which has no coral, the Actinia or sea anemone being an example of it. The second has a mere internal basis, horny or stony or both, on which the soft body is extended, as in the Corallum or Red Coral, and Gorgonia and Isis. The third includes the true Corals, or those that have a calcareous skeleton formed within the body of the animal, and these are again subdivided into groups according to the structure of the corals.

One of these groups is called Tabulata, because the cavities of the corals are divided by horizontal tabulæ,—the vertical septa being rudimentary. This group is the one most allied to the distinct order Rugosa, in which the cavities have also horizontal tabulæ very conspicuous, together with equally conspicuous vertical septa. The tabulate

Zoantharia, however, have their septa multiples of six, and not of four like the Rugosa. The extinct genera Favosites, Halysites, and Michelinia, are examples of Zoantharia Tabulata, of which some other genera have always existed during all geological periods, and four are found in the present seas.

Another group of Zoantharia is called Perforata, on account of the body of the corals being porous. They have no horizontal tabulæ. The genera Madrepora and Porites belong to this group.

Another, and by far the largest group, is called Zoantharia Aporosa, because the septa are completely lamellar, and the walls seldom porous, but forming a perfect sheath for the body. The old genera Turbinolia, Oculina, Astræa, and Fungia (now divided by M. Edwards, and J. Haime, and others, into no less than 152 genera), are examples of this group.

The Zoantharia Perforata and Aporosa include all the existing coral-forming Zoantharia, and the great bulk of those which lived in the Secondary and Tertiary epochs.

The Silurian corals are chiefly Rugosa (such as *Acervularia*, *Cyathophyllum*, and *Zaphrentis*) and Zoantharia tabulata.

Many of the Silurian and other Palæozoic corals so resemble modern genera in external form and appearance that they were at one time classed among existing genera, until more exact observation shewed many of them to be in fact members of a totally distinct order, all the genera of which have long since perished from the earth.

Extinction of Forms.—It remains only to call attention to the following genera, which, having commenced during the Lower Silurian, and survived into the Upper Silurian Period, now became extinct.

Actinozoa, Halysites, Nebulipora.
Polyzoa, Graptolithus, Ptilodictya.
Brachiopoda, Obolus, Siphonotreta.
Conchifera, Ambonychia, Cardiola, Ctenodonta, Cucullela, Lyrodesma, Modiolopsis, Orthonota, Pterinæa.
Gasteropoda, Cyclonema, Holopella.
Pteropoda, Ecculiomphalus, Pterotheca, Theca.
Cephalopoda, Lituites.
Echinodermata, Glyptocrinus, Palæaster, Protaster.
Annelida, Crossopodia, Serpulites, Tentaculites, Trachyderma.
Crustacea, Acidaspis, Ampyx, Beyrichia, Calymene, Cheirurus, Cyphaspis, Encrinurus, Homalonotus, Illænus, Leperditia, Lichas, Phacops, Sphærexochus, Staurocephalus.

The great mass of the Trilobites thus died out with the Graptolites, though unlike the latter, the family was continued by a few genera and species to still later periods.

CHAPTER XXIX.

DEVONIAN PERIOD.

THIS period is so called because certain rocks which occupy a large part of Devon are believed to have been deposited while it elapsed. All rocks which were formed after the uppermost of those which can be properly called Silurian, and before the lowest of any which can be properly called Carboniferous may be classed as Devonian rocks, and looked upon as records of Devonian time.

The rocks in Devon and Cornwall were believed to occupy this place because the fossils they contained seemed to hold an intermediate place between true Silurian and true Carboniferous fossils; they also lay below rocks which were undoubtedly of Carboniferous age. We have seen, when describing the Upper Silurian rocks, that they are covered by a series of red rocks, which are commonly called the Old Red Sandstone, and the great Carboniferous series certainly comes in over the top of this red series. The Old Red Sandstone then certainly lies between the Silurian and Carboniferous formations, and if we are to class all the rocks which occupy that position as Devonian rocks, then the Old Red Sandstone is Devonian. But the Devonian rocks south of the Bristol Channel consist of clay slates (locally called Killas), and gray limestones, with brown sandstone and flags, while the Old Red Sandstone north of the Bristol Channel consists chiefly of red sandstones and conglomerates, with nothing like gray slates or large masses of limestone. They are therefore lithologically very different kinds of rocks, nevertheless that is no reason why they should not be parts of the same formation.

The smooth gray marbles of Plymouth might geologically be identically the same as any of the coarse conglomerates of Hereford or Wales, that is, they might have been formed at precisely the same time in different places. Just as the pebble beaches of the British coasts and the coral reefs of the tropics are, as contemporaneous deposits, included in the same "Recent or Human Period," so these old dissimilar rocks might all belong to the "Devonian Period."

It is, however, quite possible that the slates and limestones of Devon, and the red sandstones of South Wales, although each deposited

within the same great period, are not strictly contemporaneous, but were formed at different parts of the period. Or it is possible that the red sandstone series of South Wales is not a continuous series—that the lower part of it, at all events, is older than any of the Devon series, while the upper part may be newer than much of that series.

It is unfortunate that up to the present time it has been found impossible to decide these questions, because in no case have the fossils of the Devon rocks been found in any beds associated with the Old Red Sandstone, or any place discovered where the two formations came into contact, so that their relations of superposition could be clearly ascertained.

There is, therefore, at present great uncertainty as to this portion of the series, an uncertainty of such a nature as to lead to a doubt whether the Devonian period will ultimately be retained. The rocks so called may perhaps hereafter be classed partly with the Upper Silurian, and partly with the Lower Carboniferous.

As the rocks called Old Red Sandstone are peculiarly British, I will first of all describe them, and then take the Devon rocks, and their equivalents abroad.

Old Red Sandstone of Siluria.—In the section, fig. 110, and in the descriptions of the Upper Ludlow rocks of Shropshire and Herefordshire, we found them passing up into a series of red flagstones and sandstones.

In Shropshire, this series of red sandstones, with bands of impure arenaceous limestone (cornstone) and occasional beds of red conglomerate, and red and green clays or marls, lies regularly and conformably upon the Upper Ludlow rocks, and dips at a gentle angle to the south-east, so as to shew a thickness of 3700 feet, when it is covered by the Carboniferous rocks of the Clee Hills.

It spreads from this district to the south-west, through Hereford into Monmouth and Brecknock, where it acquires an enormous thickness—at least 10,000 feet. It forms mountains nearly 3000 feet high (one of the Brecon Vans is 2860 feet), in which the beds lie at a very gentle angle, and shew but a small part of the formation. In this district cornstones seem to abound more near the centre and lower part of the formation, while beds of conglomerate occur in its upper part.

Proceeding into Caermarthenshire, its lower beds are tilted up into a vertical position, along with the Upper Silurians, and in the country south of Llandeilo fawr, they lie as in the following section (Fig. 111).

The lower beds are only to be separated here from the Upper Silurian by the most arbitrary line of division, founded on the gradual disappearance of all fossils as the rocks get more and more entirely red.

The uppermost red rocks, on the other hand, dip conformably

beneath the escarpment of the Carboniferous limestone, and some of the yellow sandstones and shales, which appear among the uppermost red rocks, contain fragments of plants.

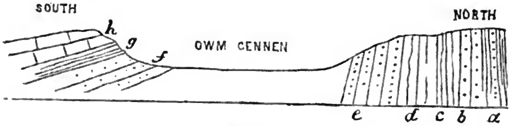


Fig. 111.

Section across Cwm Cennen, three or four miles SW. of Landeilo fawr, reduced from sec. 2, sheet 3, of the horizontal sections of the Geological Survey.

Length of section, about three miles.

		Feet.
Carboniferous.	h. Carboniferous limestone	500
	g. Lower limestone shale	100
Old Red Sandstone.	f. Red and yellow sandstones	800
	A space of nearly a mile in width, in which no rock is seen.	
	e. Red sandstones and red cellular clay rock, and cornstones	1200
	d. Laminated red and gray beds	200
Upper Silurian.	c. Laminated gray beds (Tilestone)	450
	b. White and gray sandstone (fossiliferous)	350
	a. Laminated sandstones and shales (fossiliferous)	500

Between this upper and lower part there is unfortunately the longitudinal valley of Cwm Cennen, in which no rock is to be seen; but on proceeding eastwards to the head of that valley, and crossing that of the Sawdde to the head waters of the Usk or Wysg,* the intermediate rocks are met with, and appear to connect the top and bottom of the formation, both lithologically and by their "lie," since their angle of dip gradually increases towards the Silurian country, and decreases as gradually towards the Carboniferous.

In South Wales, then, there is no apparent break in the continuity of the Old Red Sandstone, though it is difficult to explain its "position and lie" with respect to the Carboniferous rocks of Pontypool, and the Upper Silurians NW. of Usk, without supposing a separation there of some kind between the upper and lower part of the series.

Old Red Sandstone of Ireland, County Kerry.—It has been already stated that the representatives of the Wenlock and Ludlow groups can be identified by means of their fossils at the extremity of the Dingle Promontory in County Kerry. Now the rocks are there so violently disturbed, that it is almost impossible to make out the details of their structure satisfactorily, but the main facts, as exhibited in the following

* This word "wysg," by which the river is known near its head, is evidently the same as the Irish word for "water;" but I believe its meaning is now quite unknown in Wales. "Dwr," the Welsh word for water, seems allied to the Greek "hydor," while the Irish word is more like the Latin "aqua."

diagram, are clear enough. This diagram is based on the facts to be seen in two or three transverse sections across the peninsula and in the maps of the whole district, so that it represents the truth, although there is no one line of country in which all the facts given in it are to be observed together.

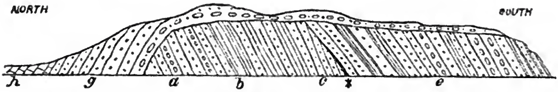


Fig. 112.

Diagramatic section representing the relation of the Dingle beds to the rocks above and below them.

h. Carboniferous limestone.
g. Old Red Sandstone, 3000 or 4000 feet.
Unconformabilty.
e. Dingle beds, sandstones, slates, and conglomerates, 7000 to 10,000 feet.
* Possible unconformability.
c. Croghmarhin beds, with Ludlow fossils.
b. Ferriters Cove beds, with Wenlock fossils.
a. Smerwick beds, red and green and yellow sandstones and conglomerates, no fossils.

The Croghmarhin beds, containing Pentamerus Knightii and other Ludlow fossils, dip south at a high angle under a great series of red and green grits and red and purple slates, with bands of purple conglomerate, some pebbles in which contain Llandovery fossils. This great series we call the "Dingle beds." Some facts connected with the general structure of the district lead me to suspect that they are not quite conformable to the rocks containing Upper Silurian fossils below them, but creep across them so as ultimately to rest on the Smerwick beds *a*. This, however, is a doubtful point, while there can be no doubt of their being above the Croghmarhin beds. The Dingle beds are clearly seen in the cliffs of the coast for several miles, dipping invariably south at an angle of 60° or thereabouts, and striking through a succession of headlands along the coast in which Ventry and Dingle Harbours lie. Mount Eagle and Brandon Mountain, the latter of which is over 3000 feet in height, are entirely composed of them.

Their thickness cannot be less than 7000 or 8000 feet, and that is not their whole thickness, since their topmost beds are nowhere to be seen. The uppermost beds that are seen strike along the cliffs of the north side of Dingle Bay for several miles, and plunge to the south into the water ; and when, as the peninsula expands, they strike into the land, they are very shortly covered by another set of red sandstones and conglomerates which rest unconformably on the edges of the Dingle beds. These overlying unconformable beds, which are undoubted Old Red Sandstone, appear at first as isolated patches on the hill tops, or as borders to the peninsula, as their beds rise from the

sea; but as we proceed towards the east or inland, they spread farther and farther towards the centre of the peninsula, and soon arch over the tops of the hills in continuous sheets, horizontal in the centre, but dipping on either hand towards the sea at higher and higher angles as they near the coasts. The Dingle and Silurian beds may be still seen beneath them for a short distance in the glens and valleys which have been worn down through the unconformable covering, as on the slope of Caherconreagh and in the Derrymore Glen; but as the hills gradually decline towards the east, and the Old Red Sandstone sinks even a little faster in that direction, the lower rocks become shortly quite concealed by it, and it itself dips conformably, and at a gentle angle, beneath the Carboniferous limestone both to the north and south, and round the eastern termination of the range, which is there called Slieve Mish.

We have here, then, two sets of red rocks which might be each called the Old Red Sandstone, since they both lie between the Upper Silurian and the Carboniferous formations, but yet are clearly separated from each other by their decided unconformability, the one adhering to and forming the upper portion of the Silurian series, the other quite separated from that, and forming the base of the Carboniferous rocks.

Old Red Sandstone of Scotland—Lanarkshire.—My colleague Mr. Geikie has lately described facts precisely similar to those just mentioned as observable in the south of Scotland. (Q. J. G. S., L., vol. xvi., p. 313.)

The green beds of the Upper Silurian near Lesmahago (see p. 483) graduate upwards, as pointed out by Sir R. I. Murchison (in his paper in Q. J. G. S., L., vol. xii., p. 17) "into a perfectly conformable series of red shales, sandstone, and conglomerate bands, which pass by alternations into a higher and very thick group of purplish gray sandstones, often pebbly and conglomeritic." In one section Mr. Geikie follows this ascending series for eight miles, and assigns it a thickness of 12,000 feet and upwards. As in Kerry, the top of the formation is nowhere reached, since it is covered unconformably by the "Upper Old Red Sandstone" and Carboniferous rocks.

Mr. Geikie shews that a similar "Lower Old Red Sandstone" rests conformably on the upper Silurian rocks of the Pentland and Lammermuir Hills, covered equally unconformably by the "Upper Old Red Sandstone" and Carboniferous rocks.

If then the separation of the Old Red Sandstone of Siluria into two distinct groups be doubtful, we have clear evidence that in Scotland and Ireland there are two distinct red series, one adhering conformably to the upper part of the Silurian series, and the other making the conformable base of the Carboniferous series, a discordant break occurring between the two of such magnitude, as to make it impossible to

consider them as parts of one formation, or include them in one common designation.

Characteristic Fossils of the so-called Lower Old Red Sandstone.—Neither the coarse sandstones and conglomerates, nor the red slates and shales, are rocks likely to contain many fossils. The remains of fish, however, of the curious genera Cephalaspis and Pteraspis, have been found in Siluria, both in the Ludlow rocks (even the Lower Ludlow) and the red Cornstone series over them. So far as the fish are concerned, the Ludlow rocks and the Red Sandstone and Cornstone series (including the Tilestone and rocks greatly above it) form parts of one formation. Here, therefore, there is neither petrological nor palæontological boundary to be drawn between the Upper Silurian and the " Lower Old Red," the only distinction being a lithological one, and that chiefly in the mere colour of the rocks. Mr. Geikie says that Cephalaspis Lyellii has also been found in the so-called Lower Old Red Sandstone of Lanarkshire.

Besides these fish, the large Crustaceans, Eurypterus and Pterygotus, have been found both in Siluria and in Scotland, in beds (the Arbroath Flagstones, etc.) which may be either Upper Silurian or Lower Old Red (*Siluria*, 3d edit., p. 277).

Unfortunately the Dingle beds of Ireland have not yet yielded to the researches of the Geological Survey any fossils whatever, except those in its pebbles which clearly do not belong to it, though I have little doubt that Cephalaspis and Pteraspis, as well as Eurypteridæ, will eventually be disinterred.

In the following fossil group, No. 11, a figure is given of one of the species of fish characteristic of the beds now described, namely—Cephalaspis Lyellii; the two others belonging to beds higher in the series, which will now be spoken of.

Old Red Sandstone proper of Caithness, the Murray Frith, Fifeshire (Dura Den), etc.—In Caithness Sir R. I. Murchison describes a great series, divisible into three groups—

3. Upper Old Red Sandstone.

2. Bituminous schists and hard flagstones, with limestones.

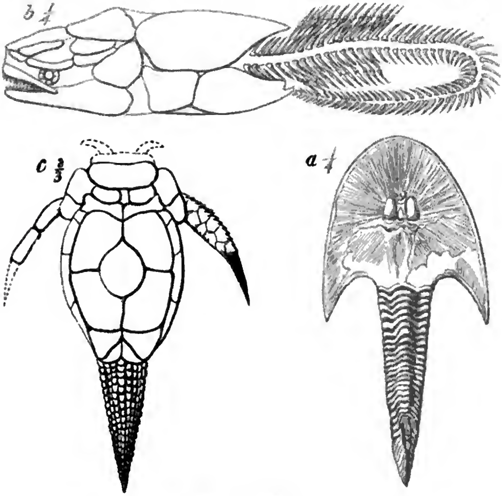
1. Thin bedded flagstone passing down into red sandstone, and that into red conglomerate.

The bottom of No. 1 rests on granite and metamorphic rocks. (*Siluria*, 3d edit., p. 280.)

No. 3 probably should be classed with the Carboniferous group.

Nos. 2 and 1 contain a number of fish of the family Acanthodidæ, and also of the following genera :—Asterolepis, Bothriolepis (fragments, probably of several different things so called), Coccosteus, Diplopterus, Dipterus, Glyptolepis, Gyroptychius, Osteolepis, Pterichthys. (*Information supplied by Professor Huxley.*)

The same group, both in Caithness and the Orkney Islands, contains a number of plants clearly of terrestrial origin, and greatly resembling Lepidodendron, Calamites, and other forms which are common in the Carboniferous rocks, but perhaps not really belonging to those genera.



Fossil Group No. 11.
Fossil Fish of Lower and Upper Old Red Sandstone.
a. Cephalaspis Lyellii. *b*. Coccosteus decipiens. *c*. Pterichthys latus.

The same beds, losing the bituminous schists, are traceable southwards along the east coast of Scotland, along both shores of the Murray Frith (Hugh Miller's country), whence a thin skirt of them strikes south-west into the great glen of the Highlands. (Sketch Map of Scotland, by Sir R. I. Murchison and Archd. Geikie.)

They recur on the coast of Forfar and Fife, whence they strike again to the south-west, along the foot of the Grampians to the Clyde, their upper beds forming apparently the "Upper Old Red Sandstone" already spoken of as lying unconformably on the so-called "Lower" Old Red Sandstone of Lanark, etc.

The following genera have been found at Dura Den, in Fifeshire—Dendrodus, Glyptopomus, Glyptolæmus, Holoptychius, Phaneropleuron, Platygnathus, Pterichthys.

Of these Pterichthys alone has yet been found in Caithness. It has also been found near Farlow in Shropshire a little below the Carboniferous limestone (*Siluria*, p. 271).

The genus Holoptychius does not occur in Caithness, but it does occur in the Carboniferous rocks abundantly, and seems, according to Professor Huxley, to be a characteristic genus of that formation.

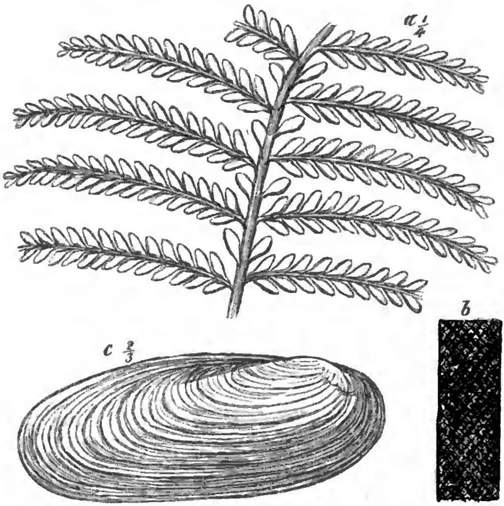
NOTE.—The Reptiles Telerpeton and Stagonolepis, which were believed to come from the Old Red Sandstone of Elgin, more probably belong to the New Red. They were found in some red sandstones which were not covered by any other rock, and therefore, may be patches of New Red Sandstone easily confounded with the Old Red Sandstone of the neighbourhood. There is little, if any distinction to be drawn between the kinds of rock, one having been confounded with the other in several English localities.

Old Red Sandstone Proper of Ireland.—In the south of Ireland, in the counties of Kilkenny, Waterford, and Cork, we get, resting unconformably on the Lower Silurian rocks, a series of red sandstones and slates, very similar to the upper part of the red series of South Wales, and like it, conforming to, and graduating up into, the Carboniferous rocks above. In Ireland, indeed, it is harder and more affected by slaty cleavage, so that the clays of Wales take the form of clay slates in Ireland. Both round the South Welsh coal-field and in south Ireland, the uppermost part of the group contains a number of beds of yellow and greenish sandstone and shale; the yellow sandstones being also so well developed in the north of Ireland as to lead Sir R. Griffith to give the name of the "Yellow sandstone" to the upper part of the series.

The Old Red Sandstone commences near Goresbridge, in Kilkenny, as a very thin band, but swells out towards the south-west in Waterford and Cork to a thickness of several thousand feet. At Kiltorcan Hill, near the village of Ballyhale, in the parish of Knocktopher, county Kilkenny, are quarries in the upper yellow or greenish sandstones, from which fronds of a fern, nearly two feet across, have been procured, together with plants of a genus called Cyclostigma, by Professor Haughton, some parts of which resemble a Sigillaria, and others Lepidodendron, and even Calamites, while its roots appear to be Stigmaria. These occur with fish scales belonging to the genera Asterolepis, Glyptolepis, and Coccosteus, and others assigned to Bothriolepis by Mr. Baily, together with a large fresh-water bivalve shell called Anodonta Jukesii by E. Forbes, and fragments of an Eurypterus. E. Forbes named the large fern provisionally Cyclopteris Hibernica; but M. Adolphe Brongniart has decided that it is more like Adiantites. (See explanation of sheets 147 and 157 of the Geological Survey of Ireland.) The Fossil Group No. 12 gives three of these species.

The Old Red Sandstone of this part of Kilkenny is about 800 feet thick, and passes quite conformably beneath the dark shales and gray

limestones of the Carboniferous series. The ferns and the Anodon have been found also near Clonmel and near Cork; and fragments of the plants always occur in the upper part of the Old Red Sandstone throughout the south of Ireland. At Tallow Bridge, in Waterford, very large stems are exposed. (See explanation of sheets 176 and 177 G. S. I.)



Fossil Group No. 12
a. Adiantites Hibernicus. b. Cyclostigma minutum.
c. Anodonta Jukesii.

The occurrence of these fossils in beds just a little below the base of the undoubted Carboniferous limestone, aids us in fixing the place of the similar beds in Scotland, in which similar fish and plants occur. The occurrence of the large fresh-water shell, so like the Anodon of our own lakes, raises a strong presumption in favour of the fresh-water character of the fish, and thus lends support to Mr. Godwin Austen's idea that the Old Red Sandstone is a fresh-water formation.

The Rocks of Devon and Cornwall.—Professor Sedgwick and Sir Roderick Murchison described the structure of North and South Devon in a paper published in vol. v., p 633, of the Transactions of the Geological Society, 2d series. Sir Roderick Murchison gives an abstract of one

of the sections of North Devon, in *Siluria*, p. 294, which includes the following groups :—

7. Culm measures ; grits, slates, and beds of culm, with a black limestone, containing Posidonomya near the base.
6. Upper Devonian bands with Clymenia limestone.
5. Red and brown arenaceous rocks (Marwood sandstone).
4. Quartzose schists.
3. Gray schists and Stringocephalus limestone.
2. Red sandstone and conglomerate.
1. Lowest beds of schist and red micaceous sandstone.

Of these the Marwood sandstone (5) contains the same fossils as occur in the Coomhola grits of Ireland, which are certainly Carboniferous.

It may be doubted, perhaps, whether 1 be not an Upper Silurian rock, from its containing Orthides, etc. If so, it would follow that 2, 3, and 4, are the only groups which ought to be called Devonian.

Professor Sedgwick, in his introduction to his British Palæozoic Rocks and Fossils, arranges the rocks of South Devon into the following groups :—

3. *Dartmouth Slate Group.*—Coarse roofing slates and quartzites, ending upwards with beds of red, green, and variegated sandstone.
2. *Plymouth Group.* { *c*, Coarse red sandstone and flagstone. *b*, Calcareous slates. *a*, Great Devon limestone.
1. *Liskeard or Ashburton Group.*

The whole of the rocks of Devon and Cornwall are greatly disturbed and contorted, often even inverted, so that in the country about the Dodman, south-west of St. Austell Bay, some of the upper rocks dip apparently beneath others which are, by their fossils, of Cambro-Silurian age (*Siluria*, p. 160). For this reason the district is one which is not well calculated to form a typical district, and any conclusions drawn from it require very strict testing and verification in other localities where the rocks have been left more undisturbedly in their original order of super-position.

The characteristic fossils of the Devonian rocks of Devonshire may be stated as follows, the Fossil Group No. 13 containing figures of some of the most remarkable :—

Spongidæ.

Stromatopora placenta . . . . Foss. gr. 13, *a*.

Actinozoa.

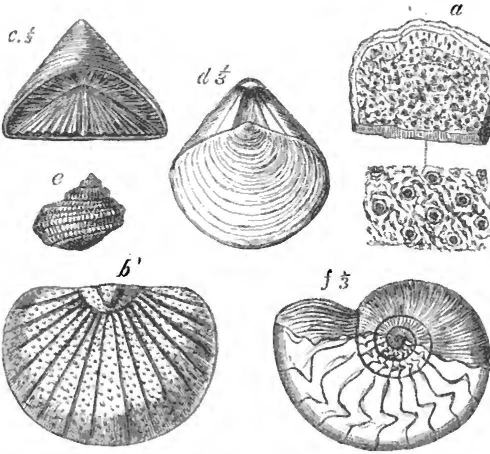
Cyathophyllum cæspitosum . . Tab. View.*

* This refers to the "Tabular View of Characteristic British Fossils," published by the Society for Promoting Christian Knowledge, price, in a book, 6s. ; a little work to which frequent reference will hereafter be made for figures of the fossils that may be mentioned.

Heliolites perosa	Phil. Pal. foss., t. 7.*
—— pyriformis	*Ibid.*
Pleurodictyum problematicum .	Tab. View.

Brachiopoda.

Atrypa desquamata . . .	Sil. foss. 75.
Calceola Sandalina . . .	Fos. gr. 13, *c*.
Orthis circularis. . . .	M'Coy, Carb. foss., t. 20.
Spirifera calcarata . . .	Tab. View.
—— speciosa	*Ditto.*
Stringocephalus Burtini . .	Foss. gr. 13, *d*, and Tab. V.
Uncites porrectus. . . .	M'Coy, Pal. foss., pl. 2 A.



Fossil Group No. 13—Devonian.

a. Stromatopora placenta.
b. Bronteus flabellifer.
c. Calceola sandalina.
d. Stringocephalus Burtini.
e. Pleurotomaria aspera.
f. Clymenia striata.

Conchifera.

Megalodon cucullatus . . .	Sil. foss. 75, and Tab. V.

Gasteropoda.

Pleurotomaaria aspera . . .	Foss. gr. 13, *e*.

Cephalopoda.

Clymenia striata	Foss. gr. 13, *f*.

* Phillips's Palæozoic Fossils of Cornwall and Devon.

Crustacea.

Bronteus flabellifer . . .	Foss. gr. 13, *b*, and Tab. V.
? Homalonotus armatus, etc.	
Phacops laciniatus.	
—— latifrons	Phil. Pal. foss., fig. 249.

Belgium and the Rhine.—Large masses of rock form the hilly region of the Ardennes between Namur and Mezieres, and stretch thence across the Rhine into Westphalia, forming the Eifel, the Hundsruck, the Taunus, and the Westerwald Hills.

The greater part of this district has been coloured in the Continental maps as Devonian (Lower, Middle, and Upper). Some of the lower rocks may be set down certainly as Lower Silurian (*Siluria*, p. 423); some of them when more minutely and accurately examined will perhaps turn out to be Upper Silurian, while the upper groups are certainly Carboniferous.

The Clymenia and Goniatite limestone, the Cypridina schiefer, and Spirifera Verneuillii schiefer, are certainly identical with the Carboniferous slate of S. Ireland, which clearly lies above the whole of a vast thickness of Old Red Sandstone there, and belongs to the Carboniferous group. It contains the Cypridina serrato-striata and Spirifera Verneuillii (so called) in great abundance, as will be shewn presently. There remain then for the Devonian rocks of Belgium and the Rhine two groups. The first and lowest of these are the "Coblentzien and Ahrien systèmes" of Dumont, which coincide with the "Spirifer sandstein" and "Wissenbach slates" of Sandberger and others. The second or upper group contains the "Calceola schist or Lenne Schiefer" of Von Dechen, the "Agger and Lenne" group of Von Dechen, F. Römer, and Girard, and the Eifel or Stringocephalus limestone.

The fossils found in these rocks in the Eifel and Rhenish country are said to be the following—

In the "Spirifer sandstein," Spirifera macroptera, and S. speciosa—Terebratula archaici, Orthis circularis, Leptæna plicata, Chonetes semiradiata, many species of Pterinea, Pleurodictyum problematicum and the Trilobites called Phacops laciniatus, and Phacops latifrons, and Homalonotus Ahrendi, and H. armatus.

The Wissenbach slates contain some of these fossils also, and some others, such as Orthoceras gracile and Goniatites compressus.

The Agger and Lenne group, and the Eifel limestone, contain—

Calceola sandalina, Spirifera cultrijugata, and others; Stringocephalus Burtini, Uncites gryphus, Megalodon cucullatus (not found in Britain, figured in Sil. foss. 75, p. 298), Lucina proavia, Murchisonia bilineata, and the corals Cyathophyllum cæspitosum, Favosites polymorpha, Heliolites pyriformis, etc. (*Siluria*, chap. xvi.)

North America.—In many parts of North America the Palæozoic rocks lie so regularly and undisturbedly, that they may probably be eventually taken as the true type of that part of the series which lies between the Silurian and Carboniferous formations.

The following groups have hitherto been described as lying above those previously mentioned at p. 484, and below others which belong undoubtedly to the Carboniferous period.

This table, taken from Rogers, is modified by that of Professor Ramsay, given in the 3d edition of *Siluria*, and that of Dr. Bigsby in Q. J. G. S., vol. xiv. The rocks seem to be all much thicker in Pennsylvania than in New York.

		Feet.
UPPER	12. Catskill group or Old Red Sandstone—red shales and gray and red sandstones	2000 to 4000
MIDDLE	11. Chemung group—gray, blue, and olive coloured shales, and gray and brown sandstones	1500 to 3200
	10. Portage group—fine grained blue flagstones, with blue shale partings .	1700
	9. Genesee slate—brownish black and bluish gray slate	30 to 300
	8. Tully limestone, according to Bigsby .	10 to 20
	7. Hamilton or Moscow shale—gray shale with dark brown sandstone . .	600
	6. Marcellus shale—black, with thin argillaceous limestone . . .	150 to 300
LOWER	5. Corniferous limestone — light gray or straw coloured, with chert nodules .	80 to 350
	4. The Onondaga limestone comes in here in New York, according to Bigsby, from	10 to 40
	3. Schoharrie grit . . .	10
	2. Caudagalli grit argillaceo-calcareous — thin bedded sandstone . .	50 to 300
	1. Oriskany sandstone . . .	70 to 700

It appears that the upper division contains fish of the genus Holoptychius, plants of the genera Sigillaria and Lepidodendron, and other fossils, from which I should at once refer it to the Carboniferous series.

The middle group contains Trilobites of the genera Phacops, Proetus, and Homalonotus, together with Dalmanites (a division of Phacops), Atrypa reticularis, and other fossils, together with, as stated, Old Red Sandstone fish, and shells of the genera Goniatites and Pro-

ducta, together with Halysites catenularis, and other Silurian forms, such as Tentaculites.

The Oriskany sandstone contains Orthis unguiformis and other fossils, and Spirifera macroptera and Pleurodictyum problematicum. (See also Dr. Bigsby's paper on the Palæozoic rocks of N. America, Q. J. G. S., vol. xiv.)

Old Red Sandstone fish, of the genera Asterolepis, etc., occur with the marine shells (*Siluria*, p. 462).

Sir W. Logan assigns a thickness of 7000 feet to the Devonian rocks of Canada, but they thin away to nothing to the southwards, as on the Mississippi the Carboniferous rocks lie directly on the Silurian (*ib.*)

Life of the Period.

While the typical rock groups assigned to this period remain in their present unsettled state, any generalizations as to the life of the period are very hazardous.

The fish that came into existence before the close of the Upper Silurian Period seem to have died out soon after that close, and were, after a long but unknown interval, succeeded by numerous other forms of fish (those mentioned at pp. 496 and 497). Some persons, Mr. Godwin Austen especially, have suggested that these were fresh-water forms: some of them, however, are apparently associated with marine forms in Russia and America (*Siluria*, p. 381, etc.), while others (Coccosteus at Kiltorcan, for instance) occur certainly in company with land plants and fresh-water shells.

There is no proof that any true Reptiles yet existed, as the Telerpeton and Stagonolepis of Scotland occur in sandstones which cannot be certainly affirmed to be Old Red Sandstone, and appear to be isolated patches of New Red.

In the limestones of Devon and the Eifel, and the rocks immediately below them, we seem certainly to have Trilobites of Silurian genera, Bronteus, Phacops, Proteus, and Homalonotus, which then died out and became extinct.

Among Brachiopod shells Spiriferæ become much more abundant, and Productæ make apparently their first appearance, while Pentameri become extinct, and the peculiar forms Calceola and Stringocephalus both commence and end their existence.

The curious Conchifer Megalodon, and still more singular Zoophyte Pleurodictyum, both appear in these rocks and in no others. Among Cephalopoda the Goniatites appears now to have come into existence, to which we must add Clymenia, if the rocks containing it are really of the Devonian Period.

Among the Corals there are many peculiar species if we are to take upon trust all the minute subdivisions and species-making of Messrs. Milne-Edwards and Jules Haime, in which, however, it appears that Mr. Lonsdale, an older and perhaps sounder authority, does not agree (*Siluria*, p. 296, *note*).

Other species might in like manner be mentioned as either surviving into the Devonian period or through it, or commencing in it and then either restricted to it or surviving into the next period, if all the published lists of fossils could be taken as trustworthy, which they unfortunately cannot.

In the better marked American series there certainly appears to be a mingling of Silurian and Carboniferous forms, together with others peculiar to this part of the series, the several groups having each a good characteristic assemblage of fossils.

The difficulties met with in the determination of fossil species are doubtless very great from natural causes, and may in some cases be even insurmountable in consequence of the gradual variation and passage of one species into another in the lapse of ages, according to C. Darwin's views. But this only increases the necessity for great caution, and for putting a severe restraint on the tendency to multiply generic and specific names. One of the greatest benefits to geological science to be derived from Mr. Darwin's philosophical speculations will probably be this union of many varieties under one specific designation, and the recognition of the variation and gradual change from one species to another, as we trace the fossils through a series of beds.

NOTE.—No more appropriate place perhaps than this will occur for a renewal of a protest against the proceedings of a certain class of palæontologists, whose sole object in life seems to be the making of new species and genera. Natural varieties, or imperfect, broken, or distorted specimens, have been made into new species, or identified with others to which they do not belong, to such an extent, as often to utterly perplex the field geologist, who looks to the palæontologist as his guide.

Where rocks are undisturbed and clear sections exist, the field geologist becomes the lawgiver, and settles the order of the rocks himself. The palæontologist learns this order from the sections of the geologist, and consequently determines the order of his fossil groups, and working with the geologist, the typical rocks and their characteristic fossils may thus be grouped and arranged as authoritative rules to guide the labours of others in other districts.

Owing, however, to the multiplicity, and the variation, in the names of the fossils, these rules are written in a language, or rather a succession of languages, which the lapse of a year or two makes obsolete or unintelligible, and owing to want of accuracy in determination, statements are derived from these rules quite at variance with fact, and leading the geologist who trusts to them into blunders which, without a false guide, he would never have committed.

CHAPTER XXX.

CARBONIFEROUS PERIOD.

THE peculiar kind of rock which we call coal is not strictly confined to any part of the series of stratified rocks, but occurs here and there in different parts of it, from the lowest to the highest. Beds of good coal, however, are much more abundant in one particular part of the series than in any other part. This is especially the case in Europe and America. The group of rocks, therefore (or formation), in which these beds of coal occur is called the Carboniferous formation, and the period of time during which that formation was being deposited may hence be called the Carboniferous period.

TYPICAL ROCK GROUPS.

IRELAND.—In no European country is the lower portion of the Carboniferous formation so well developed and so clearly seen as in Ireland.

Carboniferous Slate and Coomhola Grits.—In the preceding chapter mention was made of the Old Red Sandstone which sets in, in the counties of Kilkenny and Wexford, as a very thin deposit, but swells rapidly out in Waterford, and acquires enormous bulk in Cork and Kerry.

In the two latter counties the Old Red Sandstone consists of a vast series of green, brown, and purple gritstones, interstratified with green and purple slates. This series is covered quite conformably, as may be seen in the country round Bantry Bay, and thence by Skibbereen to Kinsale and Cork Harbour, by other grits and slates, which differ from those below chiefly in the entire absence of red colour, and the predominance of gray passing into black. This upper series has been called by Sir R. Griffith, Carboniferous slate. In Bantry Bay there is not much change in the appearance of the sandstones and gritstones about the junction of the Old Red Sandstone and Carboniferous slate, so that the boundary between them can only be at first determined by noting the change in the colour of the slate bands that lie between the grits.

Numerous sections might be drawn in many parts of the county Cork to shew the relations of these rocks, but the one in fig. 113 is taken in a part of the district frequently visited, and interesting for its picturesque beauty as well as its geology. It explains the lie and position of the beds on the east side of Glengariff Harbour, in Bantry Bay.

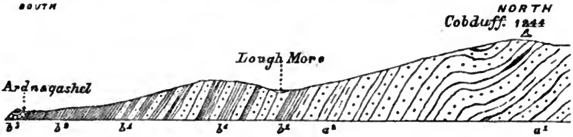


Fig. 113.

Section about 2½ miles long, from S. to N. across the hills on the east side of Glengariff Harbour, and between it and the Glen of Coomhola.

b3. Black slate with calcareous bands, full of fossils. b2. Black and gray slate, with few fossils. b1. Gray and greenish-gray grits, with interstratified black and gray slates, with marine shells and some plants (Coomhola grits).	Carboniferous Slate.
a2. Gray and greenish-gray grits, interstratified with green, liver-coloured, and purple slates, containing fragments of plants, the beds getting redder below, and plants disappearing. Cornstones occasionally. a1. Green and purple massive grits (Glengariff grits), and thin bands of purple slate. Cornstones occasionally.	Old Red Sandstone.

About Glengariff and about Bear Island, and thence to Dursey Island, and also along the south side of Kenmare Bay, from Kilmacalloge to Kilcatherine, these beds are admirably shewn. The groups called b^3 and b^2 in section 113 cannot be less than 2000 feet, and the group called b^1 (the Coomhola grit group) must be at least 3000 feet thick, so that we may state the Carboniferous slate of county Cork to have a maximum thickness of at least 5000 feet.

Characteristic Fossils.—The calcareous bands called b^3 have numerous fossils, among which are the following :—

Actinozoa.

Petraia pleuriradialis .	Phil. Pal. foss., t. 12.

Polyzoa.

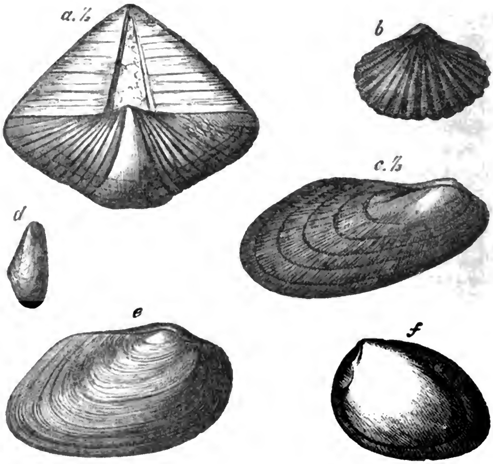
Fenestrella antiqua . .	Phil. Pal. foss., t. 12.
——— plebeia . .	*Ibid.*

Brachiopoda.

Athyris Roissyi (?) . .	M'Coy, Carb. foss., t. 21, fig. 6.
——— squamosa . .	*Phil. G. Y., t. 10, fig. 21.
Orthis crenistria . .	Phil. G. Y., t. 9, fig. 6.

* Phillips's Geology of Yorkshire.

Orthis Michelini	Phil. G. Y., t. 11, fig. 13.
——— resupinata . . .	*Ibid.* *ibid.*, fig. 1.
Producta scabricula . . .	*Ibid.*, t. 8, fig. 2.
Rhynchonella pleurodon . .	Foss. gr. 14, *b*.



Fossil group No. 14—Carboniferous Slate Fossils.

a. Spirifera cuspidata.
b. Rhynchonella pleurodon.
c. Avicula Damnoniensis.
d. Modiola M'Adami.
e. Cucullæa Hardingii.
f. Curtonotus elegans.

Spirifera cuspidata	Foss. gr. 14, *a*.
——— disjuncta (Verneuillii) .	Phil. Pal. foss., t. 29 and 30.
——— lineata	Phil. G. Y., t. 10, fig. 17.
——— imbricata . . .	*Ibid.* *ibid.*, fig. 20.
——— striata	Foss. gr. 16, *e*.
Strophomena crenistria.	

Conchifera.

Avicula Damnoniensis, . .	Foss. gr. 14, *c*.
Modiola M'Adami, . . .	Foss. gr. 14, *d*.
Nucula, *species*.	

Echinodermata.

Actinocrinus	Phil. G. Y.
Archæocidaris (plates of) . .	M'Coy, Carb. foss.
Platycrinus	Foss., gr. 18.
Poteriocrinus	Phil. G. Y.
Rhodocrinus . . .	*Ibid.*

Crustacea.

Phillipsia pustulosa . . . Foss. gr. 18, *a.*
Cypridina serrato-striata, locally in great abundance.

In the group b^1, or the Coomhola grit part of the Carboniferous slate, the following fossils have been found :—

Plants.—Stems of "Knorria" (probably portions of Cyclostigma) and other plants identical with those in the Old Red Sandstone below.

Brachiopoda.

Almost all those mentioned above, the Rhynchonella pleurodon, and Spirifera cuspidata and disjuncta, most abundantly, with the addition of a large Lingula.

Conchifera.

Avicula Damnoniensis . .	Foss. gr. 14, *c.*
Aviculopecten *species* . .	M'Coy, Carb. foss.
Cucullæa Hardingii . .	Foss. gr. 14, *e.*
——— trapezium . . .	Phil. Pal. foss., t. 19.
Curtonotus elegans . .	Foss. gr. 14, *f.*
Dolabra securiformis . .	M'Coy, Carb. foss., t. 11.
Sanguinolites plicatus . .	*Ibid.*, t. 10.
Modiola M'Adami . . .	Foss. gr. 14, *d.*
Myalina *species.*	
Mytilus *species.*	
Nucula, *large species.*	

Pteropoda or Heteropoda.

Bellerophon striatus . . Phil. Pal. foss., t. 40.
———, *rounded species, sharply keeled species, and trilobed species.*

Cephalopoda.

Orthoceras, *species.*

(See *Notes On Classification of Dev. and Car. Rocks of S. of Ireland*, by J. W. Salter and J. B. J. *Journal Dub. Geol. Soc.*, vol vii. ; and *Explan. of Sheets* 197 *and* 198 *of G. S. I.*, and forthcoming *Explan. of Sheets* 192 *G. S. I.*)

This Coomhola grit series is clearly identical with the Marwood Sandstone group of Devonshire (*ib.*), but in the south of Ireland its relation to a vast thickness of Old Red Sandstone below it, places it, in accordance with the palæontological evidence, as clearly in the Carboniferous group, and forming the base of the great Carboniferous series.

It is remarkable that the boundary between it and the Old Red Sandstone below, as drawn from lithological characters and chiefly the mere colours of the rock, is in harmony with the palæontological character of the occurrence of *marine shells.* No undoubtedly marine remains are to be found in the red rocks, but as soon as the red tints disappear, we get Brachiopoda and Conchifera of marine characters.

If the Coomhola grits be classed with the Carboniferous series, the so-called Upper Devonian of Devonshire and the Rhine (the Marwood sandstones and the Spirifera Verneuillii schists, etc.) must also be called Carboniferous.

There is, however, something very noteworthy in the mode of occurrence of the Carboniferous slate (including the Coomhola grits) in the south-west of Ireland, which may, perhaps, eventually turn out to be in harmony with a classification which should make them a distinct sub-group in combination with the upper part of the Old Red Sandstone.

If we draw a parallel of latitude through the towns of Kenmare, Macroom, and Cork, the great development of Carboniferous slate lies wholly south of that line. If we examine the neighbourhood of the city of Cork itself, we find the Old Red Sandstone with plants in its upper beds, and a very short distance above that we get solid Carboniferous limestone, with some black shales or slates between the two, but not more than 200 or 300 feet in thickness. Passing southwards to the mouth of the harbour by Monkstown or Queenstown, and then by Carrigaline and Coolmore, these intermediate black slates or shales thicken to 2000 or 3000 feet, still having the Old Red below and the Carboniferous limestone above ; but going still further south by Ringabella to Kinsale, the dark gray slates and gray grits thicken rapidly to 5000 or 6000 feet, and are nowhere covered by any part of the Carboniferous limestone, though they shew here and there highly calcareous bands.

The whole of the rocks are thrown into numerous anticlinal and synclinal curves, over many interrupted axes which strike very steadily from E.N.E. to W.S.W. ; and the headlands and bays along the south coast of Cork exhibit numerous transverse sections across the beds, so that no mistake can be made respecting the facts.

On tracing the beds round into Bantry Bay, across the anticlinal ridges of Old Red Sandstone that form Cape Clear, the Mizen Head, and Sheep's Head, we find the uppermost beds at the head of Bantry Bay

becoming actual limestone, as if the Carboniferous limestone had only just been removed from them. Following them again over the anticlinal ridge that ends in Dursey Island into Kenmare Bay, we again find the Carboniferous slate in the hollow of the synclinal,* as far as Sneem and Clonee. Beyond these points, however, the Old Red Sandstone beds, which dip beneath the waters of the bay from each side, seem to close more together, and exclude the Carboniferous slate, and when the head of the bay is reached, the flat land is composed of solid limestone, with a thickness of not more than 100 feet of black shales and grits between the base of the Carboniferous limestone and the top of the Old Red Sandstone.

The section then is like that shewn in fig. 111, where the Lower Limestone shale *g*, just 100 feet thick, is interposed between the top of the Old Red Sandstone *f*, and the Carboniferous limestone *h*.

Kenmare is not more than ten miles from Glengariff, in a direct line, so that within that distance the rocks next above the top of the Old Red Sandstone vary, as is shewn in the two sections, figs. 111 and 113, and that without any appearance of discordance or interruption, but apparently by the gradual intercalation towards the south of a series of beds 5000 feet thick, which are entirely wanting over all the country to the northward.

The little group of calcareous bands, called b^3 in section fig. 113, resembles the small group of shales that occur beneath the limestone at Kenmare, and the two sets of beds are probably the same, and form the Lower Limestone shale presently to be described—the Carboniferous slate and Coomhola grits coming in below as a distinct sub-group between the Lower Limestone shale and the Old Red Sandstone.

Carboniferous Limestone and Coal-measures.—If, after examining the Carboniferous slate, we proceed northwards through Ireland, surveying the Carboniferous rocks right and left as we proceed, we shall find that they consist at first of two groups only—viz., the Carboniferous limestone below, and the Coal-measures above.

The Carboniferous Limestone has a total maximum thickness of about 3000 feet, varying, however, in different places, especially where it rests unconformably upon an irregular surface of lower rocks.

Lower Limestone Shale.—Where its base is fully developed, it is always found to consist of beds of black shale, which we may call the *Lower Limestone shale*, generally about 150 feet thick, sometimes, perhaps, not more than 20, sometimes as much as 300. This, in the

* The headlands of the south-west of Ireland, from Kerry Head to Cape Clear, are all formed of anticlinal ridges of Old Red Sandstone, while the indentations of Tralee Bay, Dingle Bay, and Kenmare, Bantry, Dunmanus, and Roaring Water Bays, have all been worn in the more easily destructible Carboniferous rocks which lie in the synclinal troughs between the anticlinals.

absence of the Carboniferous slate, rests directly on the Old Red Sandstone, and seems even to graduate into it, the dark shales alternating with beds of yellow sandstone below, and with thin courses of limestone above.

In such places there seems to be a perfect blending and continuity between the Old Red Sandstone and the Carboniferous limestone, the Lower Limestone shale forming what would be called the passage beds, notwithstanding which there is a gap which is elsewhere filled by a deposit of at least 5000 feet thick between the two.

The Lower Limestone shale has generally a peculiar assemblage of fossils, formed of a few species that range through the limestone, but are nowhere found in such especial abundance as in this lower part of it, from which other species elsewhere abundant are absent.

These are the species mentioned at pp. 507 and 508 as characteristic of the group b^3.

The Carboniferous Limestone of the south of Ireland is perhaps one of the largest aggregates of beds of limestone to be seen anywhere in the world. The most usual character is a gray fine-grained or compact limestone, sometimes dark, sometimes light, sometimes mottled, with occasional red streaks and bands in some of the beds. In some places it contains beds of black shale, and becomes earthy in its middle portion, and sometimes the whole of it except the lower part puts on this shaly and earthy character. This middle earthy and shaly part has been called Calp, from a local term signifying "black shale."

Black chert is often developed in the limestone, rows of nodules and seams of it appearing in great abundance, sometimes in one part and sometimes in another.

The Carboniferous limestone of south Ireland usually forms low gently undulating ground, and its beds are seen only in short sections, or in scattered quarries. This induced me for some time to doubt whether the real thickness was so great as appeared from these isolated indications, until in the course of the geological survey we had examined the hills of Burren in County Clare, on the one side, and those of Queen's County, on the other.

In Burren especially, the upper part of the limestone is magnificently exposed. A range of hills, rather more than 1000 feet in height, sweeps for about 20 miles along the south side of Galway Bay. They are formed entirely of bare rock from the sea level to the hill tops, the only soil being found in crevices of the rock, or in patches in the hollows of the valleys. This rock is all limestone, in regular beds, which dip gently to the south, at an angle of 1¼° only,* and counting

* Mr. F. J. Foot, who surveyed this district, and myself, were enabled to determine the dip of the beds with the most perfect accuracy, by means of the heights given on the six-inch ordnance maps. In two or three places we could walk on the topmost bed of limestone

from the lowest bed that rises out on the sea-shore, to the uppermost, which caps the summit of the hills three or four miles to the southward, there must be a thickness of at least 1600 or 1700 feet of solid limestone shewn here. The beds can be perfectly traced round the promontories of the hills, and up the recesses of the valleys, through a winding line, the extremities of which are full 20 miles apart, and throughout that distance Mr. Foot informs me that there is not a trace of a fault or disturbance, or even an undulation in the beds. Terraces of 20 yards in breadth have been worn here and there on the top of some particular bed, and may be walked along for many miles round the sides of the hills and valleys, which resemble great stairs, or vast amphitheatres. They are not, however, very easy to traverse, since the rocks are so cut by several systems of joints, and those joints are so worn and opened by the action of the weather, that each exposed bed is cut into blocks by deep fissures, and the uppermost blocks are often loose and tottering, and worn into rough knobs and holes by the mechanical and chemical action of the weather.* Throughout the thickness of 1600 feet, but one band of chert nodules is to be seen, and not a single inch of shale or any other rock but gray limestone, every bed of which seems to be composed mainly of the minutely broken fragments of the joints of encrinites.

The upper part of the limestone thus admirably exposed in this hill country, forms probably about half the whole formation, the lower portion spreading to the east over a low country, from beneath which the Old Red Sandstone rises gently out on to the hills called Slieve Boughta.

In some other districts, as for instance in Limerick and the south of Clare, Mr. Kinahan and Mr. Foot could have divided the Carboniferous limestone into three or four subordinate groups by lithological characters, which were constant for many miles, and in the neighbourhood of Dublin Mr. Du Noyer and I have divided it into two, an upper and a lower limestone. None of these subdivisions, however, have any more than a local character, and none of them are supported by palæontological

with a little cliff of coal-measure shale close to us resting on that bed, for distances of half or three-quarters of a mile down the gentle slope of the dip, from the spot where one altitude was given to that where another appeared on the map—the difference of the altitudes, of course, giving us the fall in the distance traversed. This was always 1 in 41, which is almost exactly 1½°.

* The picturesque atmospheric effects of sunshine and cloud upon these hills of pale gray stone, with their sculptured tops and terraced sides, and their deeply-winding valleys, along which the slightly-inclined lines of stratification recede to the vanishing point, are often most peculiar, and such as I never saw in any other part of the world, while the setting sun converts the pale gray into exquisite tints of violet and rose colour. The detached outlying hills often resemble, at a distance, vast fortresses with long sloping stone glacis, from which numerous curtain-walls rise at intervals, one above another, till they terminate in a small citadel at the top.

characters depending on time, but only by such as depend on the nature of the place of deposit.

Coal-measures.—Over all the south of Ireland the Carboniferous limestone is succeeded by a series of black shales and gray gritstones or flagstones, containing in their upper portion thin beds of coal.—(See section, fig. 114.)

These Coal-measures may be subdivided, as they are in this section, into three sub-groups.

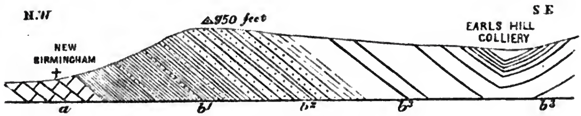


Fig. 114.

Section of the Slievardagh Coalfield, County Tipperary.

Length of section, about 1½ mile.	Feet.
$b3$ Black shales and gray grits containing nine small beds of coal . . .	1300
$b2$ Flagstone series (gray sandy flags with black shales)	700
$b1$ Black shales, with occasional bands of thin grit	800
a Carboniferous limestone.	2800

These sub-groups are recognisable throughout the counties of Cork, Limerick, and Clare, Tipperary, Queen's County, Carlow, and Dublin, wherever a sufficient thickness of the Coal-measure group comes over the limestone. The lower one, b^1, has a very distinct assemblage of fossils, which always occur in it, and sometimes in the greatest profusion, and in the most excellent state of preservation. These fossils are the following:—

Aviculopecten papyraceus . .	Koninck, t. 5.
———— variabilis . .	M'Coy, Carb. foss.
Lunulacardium Footii . . .	Expl. 142, G. S. J.
Posidonomya Becheri . . .	Phil. Pal. foss., t. 20.
———— membranacea . .	M'Coy, Carb. foss., t. 13.
Goniatites sphæricus . . .	Phil. G. Y., t. 19.
Orthoceras scalare . . .	Goldfuss.
———— Steinhaueri . .	Phil. G. Y., t. 21.

The flagstone series, b^2, is equally characterized by tracks of marine animals (mollusca or annelida), sometimes of the most remarkable character, the whole surface of large slabs being a matted network of long tortuous impressions, indentations on the upper surface, and ridges or casts of indentations, on the lower surfaces of the flagstones. (See Mr. Baily's Palæontological Notes in the Explanation of sheets 102 and 112, and 141 and 142 of G. S. I.)

If we tabulate the groups of the Carboniferous formation as it exists in the south of Ireland, and give each group its maximum thickness, we shall have the following series:—

		Feet.	
3. Coal-measures.	c. Shales, etc., with coal . .	1800	
	b. Flagstone series . . .	500	
	a. Lower shales . . .	800	
		——	3100
2. Carboniferous Limestone.	b. Subdivisions varying in different parts	2800	
	a. Lower limestone shale .	200	
		——	3000
1. Carboniferous Slate.	b. Black slate	2000	
	a. Do., with Coomhola grit .	3000	
		——	5000
Yellow sandstone, or Upper Old Red Sandstone, 800 or			900
			12,000

North of Ireland.—In the north of Ireland, according to the map of Sir R. Griffith, the Carboniferous formation is capable of still further sub-division, and consists of the following groups:—

		Feet.	
2. Coal-measures.	Coal-measures	2000	
	Millstone grit	500	
		——	2500
1. Carboniferous Limestone.	Upper limestone	500	
	Upper calp shale	500	
	Calp sandstone	300	
	Lower calp shale	500	
	Lower limestone	800	
	Lower limestone shale . .	100	
		——	2700
Yellow sandstone			500
			5700

The principal differences between the north and south are in the development of thick sandstones in the lower part of the Coal-measures in the north, forming a group like the Millstone grit of Derbyshire, and the separation of the Carboniferous limestone by the development of a set of shales and sandstones called "the Calp" in its central portion, and the entire absence of the Carboniferous slate group. The coals also in the upper part of the Coal-measures are good coals, of the character called bituminous, while those of the south of Ireland are more anthracitic.

The Carboniferous series, as thus described, may be seen in the counties of Leitrim, Fermanagh, and Armagh.

Great Britain.—In examining the Carboniferous series of Great Britain, the simplest way will be to commence on the south, as in Ireland.

Devon and Cornwall.—In this district we have a certain resemblance to the county Cork. It is probable that a large part of the slates called killas are of the age of the Old Red Sandstone. They are coloured in all late geological maps (*ex. gr.*, those of Greenhough, Murchison, and Ramsay) with the Old Red Sandstone colour. Some of them, however, including the Marwood sandstones, are certainly of the same age as the Carboniferous slate of Cork. Over these come a series of slates containing Carboniferous plants and beds of Culm, with a band of limestone here and there in their lower part. This limestone contains Posidonomya and other fossils, from which it has been paralleled with the great Carboniferous limestone, and over it are beds of sandstone supposed to represent the Millstone grit. Possibly the Culm-measures of Devon may hereafter turn out to be the representative of the lower Coal-measures only, resting, perhaps unconformably, on the Carboniferous slate rocks.

South Wales.—The section given in fig. 111, and the one which follows (fig. 115), will explain the structure of the great South Welsh coal-field, and the neighbouring ones of the Forest of Dean and Bristol.

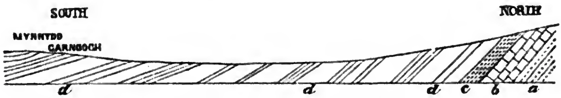


Fig. 115.

Diagrammatic section across the northern edge of the coal-field of S. Wales.

This is deduced (omitting the flexures of the beds and other details) from sheet 8 of the horizontal sections of the Geological Survey, drawn across the centre of the field between Swansea and Llandeilo fawr, by Sir W. Logan.

	Feet.
d. Coal-measures, with 50 beds of coal varying from 6 inches to 6 feet	9600
c. Farewell rock (Millstone grit)	400
b. Carboniferous limestone	600
a. Old Red Sandstone.	

In fig. 115 no notice is taken of the shaly base of the Carboniferous limestone, which nevertheless exists as drawn by Professor Phillips in section fig. 111, and is a constant member of the series throughout the district, as it is over the south of Ireland. (See also sections in *Mems. Geol. Survey*, vol. i.)

The general description of the formation in this district may be given as follows, assigning the maximum thickness to each group :—

		Feet.
4. Coal-measures	. . .	7000 to 12,000
3. Millstone grit, or Farewell rock	. .	1,000
2. Carboniferous limestone	. .	500 to 1,500
1. Lower limestone shale	. . .	200
Old Red Sandstone.		

1. The Lower Limestone shale consists of dark earthy shales, occasionally interstratified with yellowish sandstones below, and always with thin flaggy limestones in its upper part. It seems, therefore, to graduate downwards into the top of the Old Red Sandstone, as well as upwards into the Carboniferous limestone. According to Mr. Salter, it contains precisely the same fossils as are found in it in Ireland.

2. Carboniferous limestone.—A series of compact limestones, thick and thin bedded, of various shades of gray and red, sometimes, as near Bristol, interstratified with brown, gray, and red shales below, and with shales and sandstones (often red) in the upper portion. Thickness 500 to 1500 feet.

3. Millstone grit or Farewell rock.—A series of sandstones, hard, quartzose, white or gray, and near Bristol red. Maximum thickness about 1000 feet.

4. Coal-measures.—An enormous series of alternations of many hundred beds of shales, sandstones, and coals, the latter varying from one inch to seven or eight feet in thickness, twenty-five of them being more than two feet. The total thickness of the whole group is not less than 7000 feet, and is believed in some places to be even as much as 12,000 feet. (*Mems. Geol. Survey*, vol. i., p. 202).

Near Bristol the Coal-measures are thinner, and are divisible into three sub-groups, having a central band of hard sandstones called Pennant.

		Feet.
c. Upper Coal-measures, with 10 coals	. .	1800
b. Pennant series, with 5 coals	. . .	1725
a. Lower Coal-measures, with 36 coals	. .	1565
Total Coal-measure series	. .	5090

This central band of sandstones is traceable also in South Wales, by means of a hard quartzose sandstone called Cockshoot rock.

The structure of the lower groups is also peculiar; a section of them is given in great detail from the measurements of Mr. D. Williams, in the first volume of "Memoirs of the Geological Survey." If we take the first ten divisions of that section for Millstone grit, and put the others into groups with Irish designations, they would be as follows:—

Nos.		Ft.	In.
1 to 10.	Millstone grit (partly red sandstone) .	975	9
11 to 169.	Upper limestone (the first 370 feet containing many red sandstones interstratified with the limestones) . .	576	0
170 to 296.	Calp (black and brown argillaceous limestones and shales) . . .	477	0
297 to 374.	Lower limestone . . .	766	4
375 to 489.	Lower limestone shale (Carboniferous slate)	411	0
490 to 540.	Yellow sandstone series . . .	293	10
541 to 587.	Old Red Sandstone . . .	474	7
		3974	6

In the Forest of Dean coal-field, the thicknesses given above are diminished to about one-third, or

	Feet.
Coal-measures, with 31 coals . .	2400
Millstone grit	455
Carboniferous limestone . . .	480
Lower limestone shale . . .	165

—(*Mems. Geol. Survey*, vol. i., pp. 129, 203, 206).

Midland Counties.—In the centre of England we get the coal-fields of Leicestershire, Warwickshire, South Staffordshire, and Coalbrokedale, and other smaller ones near Shrewsbury, which differ from those both north and south of them in being defective at their base. They consist principally of Coal-measures only, resting on Cambrian or Silurian rocks, without the intervention of any Old Red Sandstone or Carboniferous limestone.

Carboniferous limestone sets in again at the Northern sides of the Leicestershire and Coalbrokedale coal-fields, and the Old Red Sandstone sets in to the south of the latter, and underlies the coal-field of the Forest of Wyre, letting in a thin portion of Carboniferous limestone about the small coal-field of the Brown Clee Hill ; but the Coal-measures overlap these as they die out from the north and the south respectively, and repose indiscriminately on any lower rocks there may be.

It seems as if a narrow rocky island or chain of islands had stretched east and west across the centre of what is now England during the early part of the Carboniferous period, so that while the Carboniferous limestone was being formed in the seas to the north and south, it died out as it approached this ridge of dry land.

At the still earlier period of the deposition of the Old Red Sandstone, this barrier seems to have been wider and more persistent, and to have extended through what is now Ireland, since the Old Red

Sandstone dies away as we proceed from the south to the centre of both countries, and does not again appear except as detached patches, until we reach the centre of Scotland.

During the latter part of the Carboniferous period, however, the barrier was depressed, and the water in which the Coal-measures were deposited, extended over it, so that this upper part of the formation was spread continuously across from the regions of the south to those of the north (See *ante*, p. 304).

The North of England and Wales.—To the north of the district just mentioned, the Carboniferous formation is magnificently developed.

In North Wales and Cumberland, the base of the series may be seen resting chiefly on Upper and Lower Silurian rocks, with scraps and patches of Old Red Sandstone appearing here and there in the hollows of those rocks below the limestone.

The Carboniferous limestone is generally about 1000 feet in thickness or sometimes 1500, chiefly pure compact limestone, but taking in here and there beds of black shale. It is covered by beds of shale, with thick beds of sandstone graduating up into a series of sandstones and shales, containing beds of coal. These form the groups known as the Millstone Grit and the Coal-measures.

Pennine Chain, from Derbyshire to the Cheviots.—There rises gradually from the central plains of England a broad ridge of wild moorlands, the summits of which are often 2000 feet above the sea. This is

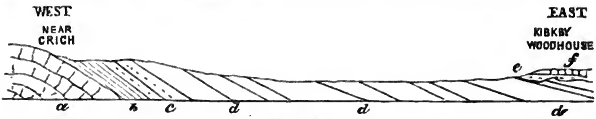


Fig. 116.

Diagrammatic section across a part of the Derbyshire coalfield.

Reduced from sheet 60 of the Horizontal Sections of the Geological Survey (drawn by W. T. Aveline), omitting flexures and faults.

Permian Rocks. { *f.* Magnesian Limestone. *g.* Rothetodtliegende (occasional).

			Feet.
Carboniferous Rocks.	*d.* Coal measures.	Beds above the Ganister set	2100
		Ganister coals and sandstones	1000
		Beds below the Ganister	600
	c. Millstone Grit.	Grits, sandstones, and shales, with thin coals	350
	b. Upper Limestone shale (black shales)		250
	a. Carboniferous Limestone (about)		1000
			5300

formed of a broad anticlinal curve, a good deal broken by large faults along its north-west flank towards Westmoreland and Cumberland.

In Derbyshire the Carboniferous limestone rises to the surface about the central portion of the anticlinal curve, and is deeply cut into by picturesque valleys, though the base of the series is nowhere exposed.

As the ridge sinks towards the south, the beds are overlapped and concealed by the New Red Sandstone, but on each flank of the ridge a section is shewn more or less closely identical with that given in the preceding, fig. 116.

The Coal-measures mentioned in the above section, extend from Nottingham to Leeds, on the east side of the anticlinal, while on the west side they form the coalfields of North Staffordshire, Cheshire, and Lancashire. In these coalfields there is a much greater thickness of Coal-measures and also of Millstone grit and Upper Limestone shale, than on the eastern side. Mr. Hull gives the following as the section of North Staffordshire in the Horizontal Sections of the Geological Survey, sheets 42 and 55 :—

	Feet.
Permian rocks	600
4. Coal-measures (in three sub-divisions)	5000
3. Millstone grit	4000
2. Yoredale rocks	2300
1. Carboniferous Limestone	4000
	15,300

The Lancashire district is stated by Mr. Hull to shew the following beds :—

	Feet.
New Red Sandstone	4000
Permian	500
3. Coal-measures (in three sub-divisions)	6800
2. Millstone grit	3500
1. Limestone shale	2000

I should be inclined to suspect great exaggeration in the thickness assigned to the groups below the Coal-measures in these places. There can, however, be no doubt as to the thickness of the Coal-measures themselves, since the sinking of vertical shafts from one coal to another at different parts as they rise towards the surface proves the total thickness.

At Dukenfield, near Manchester, a single shaft, sunk by Mr. Astley at a cost of £100,000, has a depth of 2060 feet, passing through 30 different beds of coal, having an aggregate thickness of 105

feet. Twenty-two of these coals are of workable quality and thickness.*

In Nottinghamshire, the Duke of Newcastle has lately sunk a deep shaft through the Permian rocks into the Coal-measures, of which a detailed account is given by Messrs. Lancaster and Wright, in Q. J. G. S., L., vol. xvi. p. 138. After passing through about 200 feet of Permian rocks, they sank through 222 sets of beds of sandstone, shale, and coal, with a total thickness of 1300 feet down to the Top Hard or Barnsley Coal, which was not quite 4 feet thick, and then sank and bored below that to a total depth of 1642 feet from the surface. The "Top Hard" of the Derbyshire coalfield is believed to be the same bed as the "Barnsley coal" of the Yorkshire coalfield, and it has a thickness of upwards of 2000 feet of Coal-measures below it in each place.

As we trace the Millstone grit and Upper Limestone shale from the neighbourhood of Matlock or Buxton to the north, they each seem to become more complicated, and the upper part of the Carboniferous limestone, both to the west and north, becomes split up by beds of shale, so that in Yorkshire there is a great series of alternations below the Coal-measures, consisting of shales and sandstones with thin coals in the part called Millstone grit; and shales and sandstones with thin limestones in the part called Upper Limestone shale. In Yorkshire this Upper Limestone shale and top of the Carboniferous Limestone is called the Yoredale series by Professor Phillips, and the thick limestones below are called the Scaur Limestone.

The lie of the rocks too becomes more irregular a little north of Leeds, so that the anticlinal ridge expands, and its flanks are thrown off more irregularly, so as not to bring in the Coal-measures over them (except in one small patch) on either the east or west for a space of sixty miles. On the west side, indeed, the great Cross Fell or Pennine and Craven Faults, and other large dislocations, utterly disturb the regularity of the lie of the rocks up to the Cheviot Hills; but towards the east they dip gently beneath the large Durham and Newcastle coalfield, while the outlying coalfield of Whitehaven comes in on the coast of Cumberland on the west. A section drawn across the country, from the valley of the Eden to the mouth of the Tyne, would exhibit the following series of rocks:—

	Feet.
4. Coal-measures	more than 2000
3. Millstone grit	414
2. Yoredale series	540
1. Great or Scaur Limestone group	more than 1119

* The lowest coal reached is called the "Black mine," and is 4 ft. 8 in. thick, and it was calculated as able to supply 500 tons daily for thirty years, the estate being 1263 acres. The shaft is 12 ft. 6 in. diameter, but expands near the bottom to 19 ft. 2 in. It is lined with bricks 9 in. thick, with rings of stone at intervals of 8 yards.—*Times*, 31*st July* 1858.

1. The Great or Scaur Limestone, as described by Foster in Teesdale (Phillips's *Manual*, p. 163), consists of ten sets of beds of limestone from 7 feet to 130 feet in thickness, separated by as many sets of shale and sandstone varying from 12 to 240 feet thick, the total thickness of the whole being 1119 feet, with the bottom not seen.

2. The Yoredale series contains nine sets of limestone from 2 to 30 feet thick, with as many alternations of shales and sandstone from 17 to 70 feet thick, with occasional beds of coal, the whole being 544 feet thick.

3. The Millstone grit here contains one central band of limestone called Feltop lime between alternations of sandstone, shale with ironstone, and coal, having a total of 414 feet.

4. The Coal-measures of the Tyne district (Newcastle, etc.) are about 2000 feet in thickness, containing about 600 separate beds (or measures), and a total of about 60 feet of coal. The coal lies in many beds, two of which are 6 feet in thickness, and three others 3 feet or more. A little farther north, about Berwick-on-Tweed, good beds of coal are worked down near the very base of the series in the group described above as the Great Scaur Limestone group.

Scotland.—Crossing the range of the Border Highlands into the Glasgow and Edinburgh valley, we find the Carboniferous series shewing the following groups, according to the classification of my colleague Mr. Geikie :—

	Feet.
6. *Upper Coal or Flat Coal series* of Mid-Lothian, sandstones, shales, and coals . . .	1800
5. *Moor Rock or Roslyn Sandstone*, thick, white, and reddish sandstone	1500
4. *Lower Coals and Upper Limestones*, alternations of sandstones, shales, and coals, with some beds of crinoidal limestone in the upper part of the group. This is the chief repository of the black-band ironstone and parrot coals of Scotland, about . .	900
3. *Lower Limestone or Thick Limestone Group*, consisting of several bands of crinoidal limestone of variable thickness, with interstratified shale and sandstone and one or two seams of good coal, about . .	200
2. *Calciferous Sandstone or Lower Carboniferous series*; a very thick group of sandstones, with some shales, and a number of thin limestone bands.	
1. *Upper Old Red Sandstone*, red and yellowish sandstones. marls, and conglomerates, with some cornstones.	

Of these groups No. 1 may be seen in Berwickshire, Haddington and Fife shires (Dura Den, etc.) It is obviously identical with the upper part of the Old Red Sandstone of Siluria and south Ireland (the Kiltorcan beds, etc.)

No. 2 Is probably the same as the Carboniferous slate and Coomhola grit of south Ireland, and, therefore, as the Marwood sandstone group of Devon.

It is very thick towards the east, but thins out rapidly towards the west, and disappears in Ayrshire.

No. 3 Is the Great Scaur Limestone group of Durham, but still more split up by shales and sandstones, and contains beds of coal. It is on the same horizon with the bottom part of the Carboniferous limestone of Derbyshire, etc., and the Lower Limestone of Ireland.

No. 4 Is obviously identical with the Yoredale series of Yorkshire, and, therefore, with the Upper Limestone shale of Derbyshire, and probably with the Calp and Upper Limestone of Ireland.

No. 5 Is believed to be the representative of the Millstone grit of north England and Ireland, the Farewell sandstone of South Wales, and probably the lower part of the Coal-measures of the south of Ireland (viz., groups 6^1 and 6^2 in fig. 114).

No. 6 Agrees with the lower part of the Coal-measures of England and Wales, and the upper part of the Coal-measures of south Ireland.

Igneous Rocks Associated with the Carboniferous Series.

Ireland.—Advantage was taken in chapter xviii. of the description of contemporaneous trap rocks to mention those in the Carboniferous limestone of the Limerick basin (p. 325), turning to which the reader will see proofs of the existence of igneous eruptions having burst out in the Carboniferous sea, and produced great beds of trap and ash, about the middle of the Carboniferous limestone, and also near its summit.

Derbyshire.—In Derbyshire there are one or two widely-spread bands of igneous rock called toadstone, in the Carboniferous limestone. These are certainly contemporaneous traps, and I had long been under the impression, from observations made in the years 1837 and 1838, that each of these toadstone bands was the result, not of one simultaneous ejection of igneous matter, but of several, proceeding from different foci uniting together to form one band. This belief was confirmed in 1861 on visiting Buxton with the eminent Swiss geologists, Messrs. Escher and Merian, and their companion M. Stöhr, when the railway cutting a little below Buxton, down the valley of the Wye, laid open the toadstone, with the limestone above and below it. Two solid beds of toadstone were exposed, proceeding from opposite ends of the cutting, towards each other, but not overlapping, with beds of purple and green ash, greatly decomposed into clay, both above and below each

bed, and between the two, the whole forming a rather irregular composite accumulation, with a total thickness of about 50 feet.

North of England.—Farther north, in Yorkshire, Durham, and Northumberland, great beds of basalt lie in the Carboniferous limestone series, one called the Great Whin sill, extending for many miles, and varying in thickness from 20 to 300 feet. Professor Sedgwick believes this to have been a mass horizontally injected between the beds; but Professor Phillips says, that "we cannot doubt that it was erupted from several centres or lines," and speaks of the possibility of its having been poured "out as a mass of submarine lava." (Phillips's *Manual*, p. 522.) It alters the rocks below it, so that the black shales become prismatic, and in some places contain garnets. If the rocks above are also altered, it must of course be intrusive.

Are the igneous rocks of the Cheviot Hills of Carboniferous date?

Scotland.—The Carboniferous rocks of Scotland are full of traps, both contemporaneous and intrusive, and of both felstone and greenstone character. Beds of ash accompany many of the contemporaneous traps. Those of the neighbourhood of Edinburgh, included in sheet 32 of the geological map of Scotland, are now fully described by Messrs. Howell and Geikie, in the Mems. of the Geol. Surv. Great Britain, in the part entitled, "Geology of the Neighbourhood of Edinburgh."

Characteristic Fossils.

A list has been already given of the characteristic fossils of the lower part of the series in Ireland. Some of the fossils there mentioned, however, are not restricted to that part, but occur throughout the Carboniferous series, and will be mentioned again in the following list.

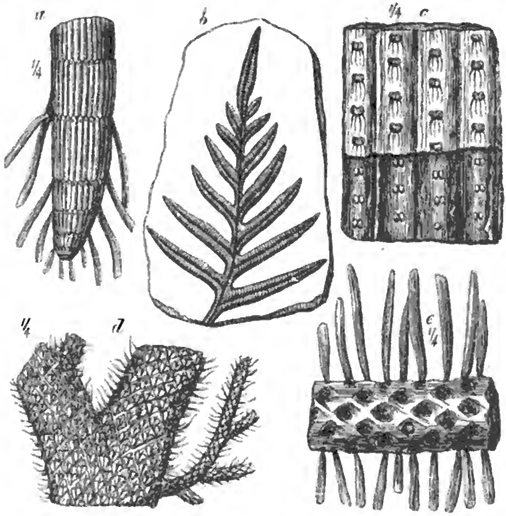
One general characteristic of the formation is the abundance of plants. These occur throughout, and are not, I believe, characteristic of one part of it more than another, except that they are found in shales and sandstones, or the washings of the land, rather than in limestones, the product of the ocean.

It does not appear that there is any essential difference in Scotland between the plants found with the coals at the base of the series, and those found near the top, some species being locally peculiar in each case, but occurring in other beds in other places. Similarly, although the marine shells, etc., are found principally in the limestones, as might be expected, yet they are found occasionally in the shales and sandstones in which coals occur, together with other shells that look something like fresh-water shells, but nevertheless may be marine.

The different assemblages of fossils, therefore, found in different parts of the Carboniferous series, may be only locally characteristic of those parts, their limitation depending on the nature of the "station" in which, and not upon the time during which, they lived.

Plants.

Alethopteris lonchitica (Fern) .	.	Foss. gr. 15, *b*.
Asterophyllites equisetiformis		
——— foliosa	.	Tab. V., and Ly. Man.,* p. 369.
Calamites cannæformis . .	.	Foss. gr. 15, *a*.



Fossil Group No. 15.
Carboniferous Plants.

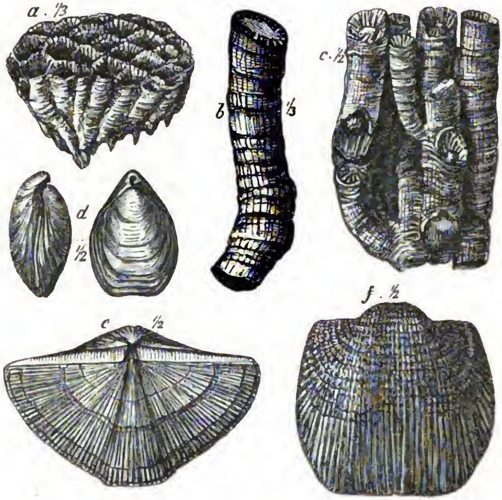
a. Calamites cannæformis.
b. Alethopteris lonchitica.
c. Sigillaria reniformis.
d. Lepidodendron elegans.
e. Stigmaria ficoides.

Lepidodendron elegans . .	.	Foss. gr. 15, *d*.
Lepidostrobus ornatus . .	.	Ly. Man., p. 366, and Tab. V.
Neuropteris gigantea (Fern) .	.	Tab. View.
Sigillaria reniformis . .	.	Foss. gr. 15, *c*.
Sphenopteris crenata (Fern) .	.	Ly. Man., p. 364, and Tab. V.
Stigmaria (roots and rootlets) .	.	Foss. gr. 15, *e*.

* The Tabular View of Characteristic British Fossils, and Lyell's Manual of Elementary Geology, fifth edition.

Actinozoa.

Amplexus coralloides	Foss. gr. 16, *a*.
Lithostrotion affine	Foss. gr. 16, *c*.
Michelinia favosa	Foss. gr. 16, *a*.
Syringopora ramulosa	Tab. View.



Fossil Group No. 16.
Carboniferous Fossils.

a. Michelinia favosa.
b. Amplexus coralloides.
c. Lithostrotion affine.
d. Terebratula hastata.
e. Spirifera striata.
f. Producta semireticulata.

Polyzoa.

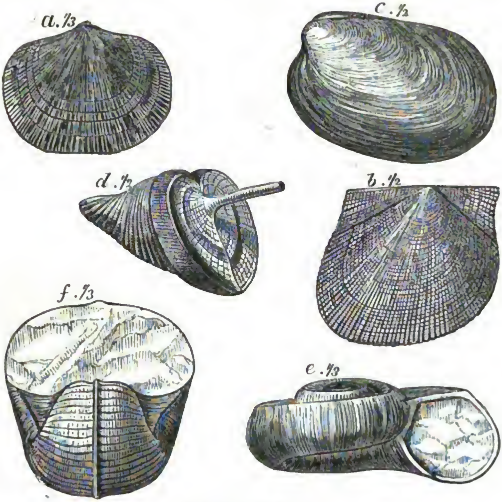
Fenestrella antiqua, membranacea, plebeia, etc. Phil. G. Y. and Pal. foss.

Brachiopoda.

Athyris Royssii	*M'Coy, Carb. foss., t. 21, fig. 6.
Discina nitida	Phil. G. Y., t. 11, fig. 10.

* Phillips's Geology of Yorkshire and Palæozoic Fossils; and M'Coy's Carboniferous Fossils, published by Sir R. Griffith.

Orthis resupinata	Foss. gr. 17, *a.*
Producta aculeata, scabricula, etc. . .	Phil. G. Y.
—— semireticulata * . . .	Foss. gr. 16, *f.*
Rhynchonella acuminata . . .	Tab. View.
—— pleurodon	Foss. gr. 14, *b.*
Spirifera cuspidata	Foss. gr. 14, *a.*
—— glabra . . . . . :	Tab. View.
—— pinguis	Phil. G. Y.
—— striata †	Foss. gr. 15, *c.*
Terebratula hastata	Foss. gr. 16, *d.*



Fossil Group No. 17.
Carboniferous Fossils.

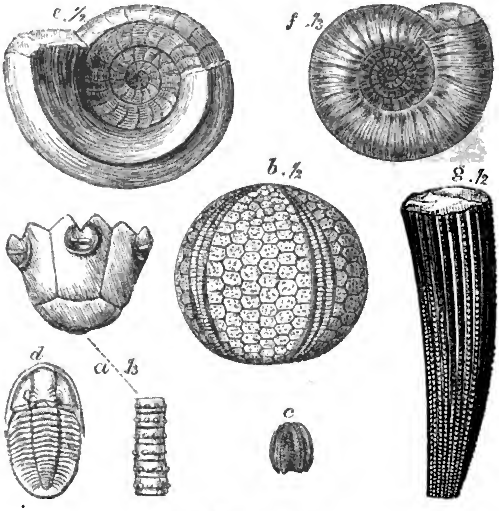
a. Orthis resupinata.
b. Avienlopeeten papyraceus.
c. Cardiomorpha oblonga.
d. Conocardium Hibernicum.
e. Euomphalus pentagonalis.
f. Bellerophon tangentialis.

* De Koninck believes P. Martini to be a variety of semireticulata ; gigantea and Scotica are probably the same.

† It is believed that many other species of Spirifera would properly be included in one or other of the above. Sp. disjuncta or Verneuillii, for instance, is probably only a variety of Sp. striata.

Conchifera.

Aviculopecten papyraceus	Foss. gr. 17, *b.*
Cardiomorpha oblonga	Foss. gr. 17, *e.*
Conocardium (Pleurorhyncus) Hibernicum	Foss. gr. 17, *d.*
Posidonomya Becheri	Tab. V. and Ly. Man., p. 414.



Fossil Group No. 18.
Carboniferous Fossils.

a. Platycrinus lævis.
b. Palæchinus sphæricus.
c. Pentremites Derbiensis.
d. Phillipsia pustulosa.
e. Nautilus biangulatus (or carinatus).
f. Goniatites Listeri.
g. Orthoceras Gesneri.

Gasteropoda.

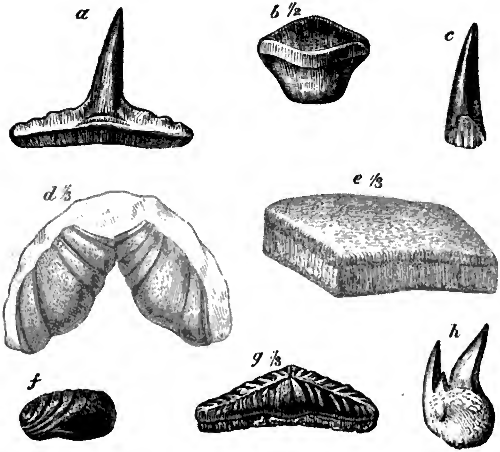
Euomphalus pentagonalis .	Foss. gr. 17, *e.*
Loxonema Lefebvrei.	
Macrocheilus ovalis . .	M'Coy, Carb. foss.
—— pusillus.	
Natica elliptica . . .	Phil. G. Y., t. 14, fig. 23.
Patella mucronata . .	Phil. G. Y., fig. 3.
Pleurotomaria carinata . .	Phil. G. Y., t. 15, fig. 1.
Trochella prisca . . .	M'Coy, Carb. foss., t. 7, fig. 1.

Pteropoda and Heteropoda.

Bellerophon hiulcus	Tab. View.
—— tangentialis	Foss. gr. 17, *f*.
Porcellia Puzio.	

Cephalopoda.

Actinoceras giganteum	G. Y. 2, t. 21.
Cyrtoceras Verneuillianum . . .	Koninck, t. 44.
Goniatites Listeri	Foss. gr. 18, *f*.
—— sphæricus	Tab. View.



Fossil Group No. 19.
Carboniferous Fish Teeth.

a. Cladodus striatus.
b. Petalodus Hastingsiæ.
c. Holoptychius Portlockii.
d. Cochliodus oblongus.
e. Psammodus porosus.
f. Pœcillodus transversus.
g. Orodus ramosus.
h. Diplodus gibbosus.

Nautilus biangulatus (or carinatus) .	Foss. gr. 18. *e*.
Orthoceras Gesneri	Foss. gr. 18, *g*.
—— Steinhaueri	Phill. G. Y. 2, t. 21.
Poterioceras fusiforme	Tab. View.

Echinodermata.

Actinocrinus triacontadactylus	Tab. View.
Archæocidaris Urii	M'C. Carb. foss., t. 27.
Cyathocrinus tabulatus	Tab. View.
Palæchinus sphæricus	Foss. gr. 18, *b.*
Pentremites Derbiensis	Foss. gr. 18, *c.*
Platycrinus lævis	Foss. gr. 18, *a.*
Poteriocrinus granulosus	Phill. G. Y. 2, t. 4.
Rhodocrinus costatus	An. Nat. Hist. 43.
Annelida.	
Spirorbis carbonarius	Ly. Man., p. 387.
Crustacea.	
Bellinurus Regina	Expl. sh. 137, G.S.I.
—— rotundatus	Ly. Man., p. 388.
—— trilobitoides	* Buckl. B. T.
Brachymetopus (Phillipsia) Ouralicus.	
Dithyrocaris orbicularis.	Port. G. R. 312.
Griffithides globiceps	*Ibid*, 311.
Phillipsia pustulata	Foss. gr. 18, *d.*
Fish.	
Cladodus striatus	Foss. gr. 19, *a.*
Cochliodus oblongus	Foss. gr. 19, *d.*
Ctenacanthus brevis	Foss. gr. 19, *h.*
Diplodus gibbosus	Foss. gr. 19, *h.*
Holoptychius Portlockii	Foss. gr. 19, *c.*
—— Hibberti	Ly. Man., p. 400.
Orodus ramosus	Foss. gr. 19, *g.*
Pæcillodus transversus	Foss. gr. 19, *f.*
Psammodus porosus	Foss. gr. 19, *e.*

Foreign Carboniferous Rocks.—On the continent of Europe the development of the rocks of this period is generally inferior to that observable in the British Islands. Having learnt the succession of the beds, and their organic remains, however, in our own country, we are enabled to trace a corresponding order in other parts.

Belgium.—According to M. Dumont—

SYSTEME HOUILLIER.	4. Alternations of "ampelite" (sandstone), shale, and coal.
SYSTEME CONDRUSIEN.	3. Crinoidal limestone, dolomite, producta limestone, with chert and anthracite. 2. Gray sandstone, soft sandstone, and anthracite. 1. Gray shales, calcareous shales, dark limestone, and pisolitic iron ore (oligiste).

* Buckland's Bridgewater Treatise.

Characteristic Fossils.—The plants of No. 4 correspond to those of our Coal-measures. The large Productæ and other fossils of No. 3, correspond in the main with those of the Carboniferous or mountain limestone of the British Islands. The lowest division, No. 1, contains Spirifers, Cyathophyllum mitratum, Pleurotomariæ, and other fossils, found also in the lower divisions of Northumberland and Scotland.

The coalfield of Liege has long been celebrated. The rocks in that neighbourhood, and about Namur seemed to me greatly to resemble those of the south of Ireland, the Coal-measures being apparently affected by slaty cleavage, thick Carboniferous limestone appearing below them, and underneath that beds resembling the Carboniferous slate.

France has Coal-measures in the coalfields of Valenciennes in the north, which is the western continuation of that of Belgium, and is covered towards the west unconformably by the Chalk ; and also in the southern coalfields of St. Etienne, and some other smaller districts. Much of the lower part of the formation, however, consists of clay slate, and altered rocks, which were at one time taken for much older formations. Sir Roderick Murchison shewed that the slate rocks of Le Foret, near Vichy, pierced by syenites and porphyries, were in reality Carboniferous rocks.—(*Q. J. Geol. Soc.*, vol. vii., p. 13.)

Carboniferous rocks occur in small detached localities in many other parts of Europe, but do not admit of description as *typical* rocks of the period. The fossils contained in them agree with those already mentioned, with just that amount of difference that might be expected to arise from the laws of geographical distribution.

Reptiles, such as Archegosaurus and Apateon, occur occasionally.

North America : Nova Scotia.—According to Mr. Dawson—

UPPER GROUP.	3. Grayish and reddish sandstone and shales, with beds of conglomerate, and a few thin beds of limestone and coal. 3000 feet and more.
MIDDLE OR GOOD COAL GROUP.	2. Gray and dark-coloured sandstones and shales, with red and brown beds, coal, ironstone, and bituminous limestone. 4000 feet and more.
LOWER OR GYPSIFEROUS GROUP.	1. Red and gray sandstones and conglomerates, and red and green marls and shales, with thick beds of gypsum and limestone. 6000 feet and more.

Characteristic Fossils.—Those of No. 1 consist of Productæ, Terebratulæ, Encrinites, and Corals, etc., in the limestones, many analagous to, and some even identical with those of the Carboniferous limestone

of Britain. Scales of Holoptychius and Palæoniscus have also been discovered. Lepidodendron and other plants occur in the sandstones.

In No. 2, Stigmaria, Sigillaria, and other genera of plants occur in abundance, generically identical with those of our Coal-measures; Cypris, Modiola, a land shell (Pupa), Ganoid fish, and three species of Reptiles also are known, apparently of terrestrial species.

In No. 3, Calamites, Ferns, and Coniferous wood are found.

Altogether there is a thickness of more than 14,000 feet, without reaching any exact base, or arriving apparently at the very highest beds of the series. There are seventy-six beds of coal, of which, however, most are only one or two inches thick, and the thickest not more than four feet.—(*Dawson's Acadian Geology.*)

Some of the beds of group 1, consisting of sandstones with variegated marls and gypsum, and a few beds of coal were seen formerly by myself in Newfoundland, on the south shore of St. George's Bay, and at the northern extremity of the Grand Pond.—(*Report on Geology of Newfoundland.*)

United States.—According to Professor Rogers.

3. UPPER CARBONIFEROUS OR COAL-MEASURE GROUP.	Coal-measures, alternations of sandstones, shales, and coals, like groups 2 and 3 of the Nova Scotia district, but thinning out westward, so as to be only 3000 feet in Pennsylvania, 1500 in the Illinois Basin, and not more than 1000 in Iowa and Missouri.
2. MIDDLE CARBONIFEROUS GROUP.	In Pennsylvania, soft red shales, and argillaceous red sandstones, 3000 feet. In Virginia— *c.* Blue, olive, and red calcareous shales, with thick red and brown sandstone. *b.* Light blue limestone, sometimes Oolitic. *a.* Buff, greenish, and red shales, with sandstone. Total thickness, 3000 feet. In the Western States— *b.* Gray and yellow sandstone. *a.* Light blue and yellow limestone,* 1000 feet.
1. LOWER CARBONIFEROUS GROUP.	White, gray, and yellow sandstones, alternating with coarse siliceous conglomerates, and dark blue and olive-coloured slates. In some places contains black carbonaceous slate, and a bed or two of coal. 2000 feet thick in Pennsylvania, thinning out to nothing in the north-west.

* The light blue limestone mentioned above thickens towards the south-west, and dies away to the north-east in Pennsylvania.

Characteristic Fossils.—Those of No. 1 are said to be coal plants in some parts, and marine remains, Crinoids, and Molluscs, in others. It may possibly be the equivalent of the Carboniferous slate of Ireland and Marwood beds of Devon.

Those of No. 2 are like those of No. 1 of the Nova Scotia district, generically identical with the fossils of the Carboniferous limestone of Britain.

Those of No. 3 are in like manner coal plants, belonging to the same generic forms as the British, but with many local and peculiar species. The marine beds contain corals, shells, and fishes, and the littoral beds show the tracks of reptiles of the order Labyrinthodontidæ.

India.—Several large and important coalfields exist in India, as those of Damoodah, Talcheer, Nagpur, and others. There is, however, much doubt whether these are really of the Carboniferous period, since they contain fossil plants of the genera Pecopteris, Glossopteris, Vertebaria, Phyllotheca, etc., which are believed to be rather of Triassic or Oolitic age than of the Carboniferous. (See papers by T. Oldham, Mems. Geol. Survey India, vol. i.; and by Sir C. Bunbury in Q. J. Geol. Soc. vol. xvii.)

Australia—There are large formations in Australia which are certainly of Upper Palæozoic age, consisting of sandstones, shales, and limestones, containing shells of the genera Producta, Spirifera, Leptæna, Orthonota, Pecten, Pterinea, Pachydomus, Platyschisma, Bellerophon, Conularia, stems of Crinoids, a small Tribolite, etc. etc. Associated with these rocks, and apparently forming the upper part of them, are other shales and sandstones of precisely similar character, containing good beds of coal, and having fossil plants of the genera Glassopteris, Tæniopteris, Pecopteris, Phyllotheca, Vertebraria, etc., precisely like those of India. These coal-bearing beds are accordingly believed by some persons to be of much later date than the beds below them, which contain palæozoic genera of animal remains.

I certainly could see no reason myself, in Tasmania and New South Wales, for introducing any separation among these beds, which seemed to be all part and parcel of the same great formation of pale sandstones, separated by shales, and containing calcareous beds in the lower part, and coal beds in the middle part of the formation.

In New South Wales the beds are all nearly horizontal, and the section quite clear, as described by myself in a paper in the *Quarterly Journ. of Geol. Soc.*, vol. 3, of which the following is an abstract. (See also *Sketch of Phys. Structure of Australia.* Boone.)

5. Dark brown shales, with impressions of plants . .	300 feet and more.

4. Sydney sandstone, thick white or light-yellow sandstone, with quartz pebbles occasionally, and partings of shale	700 feet.
3. Alternations of shales and sandstones	400 feet.
2. Shales containing two or three good beds of workable coal, 6 feet thick	200 to 300 feet.
1. Wollongong sandstones, thick dark-gray, reddish-brown, often calcareous, with large calcareous concretions .	400 feet and more.

This is only a part of the series, as there may be beds below No. 1, and others above No. 5.

Characteristic Fossils.—Those of No. 1 are, Stenopora crinita ; Producta rugata ; Spirifera subradiata, Stokesii ; and Avicula, Pachydomus, Orthonota, Pleurotomaria, Bellerophon, etc.

Those of No. 2 are, Glossopteris Browniana ; Vertebraria indica ; Pecopteris australis ; Phyllotheca australis.

There are fish said to have been found by Mr. Clarke in No. 3 or 5, together with fragments of plants. No fossils have yet been found in No. 4.

The Rev. W. B. Clarke has also written largely on the structure of this country in the *Quar. Journ. Geol. Soc.*, and in separate publications. He proposes the names of Hawkesbury Sandstone for the group No. 4 of the above section, and Waianamatta Shales for group No. 5.

The city of Sydney stands on beds about the junction of 4 and 5, so that the coal beds of Hunter's River and Illawarra lie underneath it at a depth of about 1200 feet. Mr. Clarke's Waianamatta shales form the surface rock of the great part of the county of Cumberland, the Sydney or Hawkesbury sandstones cropping out all round it, both along the coast and in the Blue Mountain range in the interior, and the coals are everywhere found a little below the base of this sandstone, both on the south at Illawarra, on the north at Hunter's River, and in the gullies of the Blue mountains, according to Count Strzelecki.

Life of the Period.

The unsettled state of the boundary between the rocks that should be referred to the Devonian, and those that are clearly of the Carboniferous period, produces a corresponding hesitation as to the period of the commencement of certain genera of fossils.

The Carboniferous period certainly abounded in plants that were well adapted for preservation and for conversion into coal. It cannot be said with certainty whether the greater abundance of coal was the result of a peculiarity in the physical geography of the time being unusually favourable to vegetable life, or of the kind of vegetation being peculiarly adapted to form coal.

It has been suggested that the atmosphere previously contained more carbonic acid gas, and that it was comparatively cleared of it during the period, by the " fixation" of carbon in the form of coal. In these speculations, however, attention seems to have been paid solely to the carbonic acid of the atmosphere, without taking any account of the vast quantity of carbon that must always have been " fixed," as it is called, in the vegetables and animals that clothed and peopled the earth. No reliable data exist for estimating, with any approach to accuracy, the coal now buried in the earth, but supposing an accurate estimate were to be formed of the carbon in the form of coal, we should require to know the quantity of carbon in existing plants, and the smaller, but still appreciable quantity, in existing animals. If we choose to indulge our fancy in imagining that in the periods of the earth's history previous to that called the Carboniferous period, there was no coal and no terrestrial vegetation, we may, if we like, fancy still further, that the carbon afterwards used for them existed previously as carbonic acid in the atmosphere, and that the earth was enveloped in an atmosphere like that of the Grotto del Cane ; but the speculation must always remain a fanciful one.

It would seem, from some experiments by Messrs. Lindley and Hutton, that the plants found so abundantly in the Carboniferous rocks belonged to classes peculiarly adapted for preservation when buried under water, and that there may have been therefore an equal abundance of other plants which have not been preserved.—(*Lindley and Hutton's Fossil Flora.*)

The following are the genera of plants which appear to have first come into existence during the Carboniferous period ; those marked with an asterisk being apparently confined to it, the others surviving into the Oolitic period, and one or two to still later times.

Plants.—* Adiantites, Alethopteris, * Anabathra, * Annularia, * Antholites, * Aphlebia, * Aspidaria, * Asterophyllites, Calamites, *Cardiocarpon, Carpolithes, *Caulopteris, * Crepidopteris, * Cyclocladia, Cyclopteris, * Cyperites, * Dadoxylon, Endogenites, Flabellaria, * Halonia, * Hippurites, * Hydatica, Hymenophyllites, * Knorria, Lepidodendron, *Lepidophyllum, *Lepidostrobus, *Lomatophloyos, Lycopodites * Lyginodendron, * Megaphytum, * Musocarpum, * Myriophyllites, Neuropteris, * Næggerathia, * Odontopteris, Otopteris, * Palmacites, * Picea, Pinites, * Pinnularia, * Pitus, * Poacites, * Polyporites, * Pothocites, * Protopteris, * Rhabdocarpus, * Sagenaria, * Selaginites, * Sigillaria, Sphenophyllum, Sphenopteris, * Sternbergia, * Stigmaria, * Trigonocarpium, * Ulodendron, Walchia.

Of these, many are ferns, and some are supposed to have been huge Lycopodiaceæ, others are of unknown affinities. Mr. Salter at the last meeting of the British Association (Manchester 1861) offered

remarks tending to prove Sigillaria was a great aquatic, possibly a marine, plant. It has often occurred to me that the amomalies arising from the evidence for the growth in situ of many coal plants, and the interstratification of the coals with beds formed under water, would be got by supposing these plants to have grown in the water, and formed beds at the bottom of it.

The following genera of animals seem to date their existence from this period, those who perished with it being likewise distinguished by an asterisk.

Actinozoa, *Amplexus, *Aulophyllum, *Axophyllum, *Beaumontia, *Campophyllum, Fistulipora, *Heterophyllia, *Lithostrotion, *Lophophyllum, *Michelinia, *Mortieria, *Petallaxis, *Phillipsastræa, *Pyrgia, *Rhabdopora.

Polyzoa, *Sulcoretepora, Vincularia.

Brachiopoda, Camarophoria, Producta,[1] Terebratula.

Conchifera, *Aviculopecten, Anodonta, ?Anatina, *Anthracosia, ?Axinus, Cardinia, Cardiomorpha, Cucullæa, Edmondia, Inoceramus (or shell having similar external form) Leda, ?Lima, Lithodomus, Lucina, ?Lutraria, Mactra, Myacites, Myalina, ?Pandora, Pleurophorus, Sedgwickia.

Gasteropoda, Buccinum, Cylindrites, Dentalium, Eulima, Lacuna, Littorina, ?Melania, *Metoptoma, Patella, *Phanerotinus, *Platyschisma, ?Pupa, *Trochella, Vermetus.

Cephalopoda, *Clymenia, *Goniatites, Nautilus, *Poterioceras, *Trigonoceras.

Echinodermata, *Adelocrinus, Archæocidaris, *Astrocrinus, *Atocrinus, *Codonaster, *Cupressocrinus, *Dichocrinus, *Euryocrinus, *Mespilocrinus, *Pentremites, *Perischodomus, *Platycrinus, *Sycocrinus, *Synbathocrinus, *Woodocrinus.

Annelida, Sabella, Serpula, *Spiroglyphus, Spirorbis.

Crustacea, Bairdia, *Bellinurus (or Limulus) *Brachymetopus, *Cyclus, Cythere, Cypris, *Entomoconchus, *Griffithides, Macrura, *Phillipsia.

Insecta, Curculioides, Corydalis.

Fish, *Amblypterus, *Asteroptychius, *Carcharopsis, *Cheirodus, *Chomatodus, *Cladodus, *Cochliodus, Cælacanthus, *Colonodus, *Cricacanthus, *Ctenodus, *Diplodus, *Dipriacanthus, *Erismacanthus, *Eurynotus, *Glossodes, Gyracanthus, Gyrolepis, Helodus, *Holoptychius, *Homacanthus, *Lepracanthus, Lepta-

[1] A fashion has lately crept in of calling this Productus. It seems to me we might as well speak of a Terebratulus, an Atrypus, or a Rhynchonellus. Where a Latin adjective is employed as a name of a bivalve shell, it should always be made to agree with Concha or Cochlea understood, and only have a masculine or neuter termination when a substantive is used, as in the case of Pentamerus. The shell was originally called Anomia producta, and afterwards Producta alone; why not let it remain so?

canthus, * Megalichthys, * Oracanthus, * Orodus, * Orthacanthus, Palæoniscus, * Petalodus, * Pterodus, * Physonemus, * Platycanthus, Platysomus, * Plectrolepis, * Pleuracanthus, * Pœcilodus, * Polyrhizodus, * Psammodus, * Psammosteus, Pygopterus, * Rhizodus, * Sphenacanthus, * Tristychius, * Uronemus.

Reptiles, Archegosaurus.

In examining these lists of new genera, we are first met by Corals, some of which grow to large size—a foot or two in diameter.[1] They occur sometimes in beds, a number of species growing together and forming a regular wide-spread coral bed, that might be likened to a small fringing or shore reef. They may, however, perhaps have been deep-water species, and at all events there is not the slightest appearance of any approach to the form of one of the Atoll or Barrier reefs of the present day, either in the Carboniferous or any other Palæozoic limestones. "With the exception of the genus Pyrgia, all the Carboniferous corals are Rugosa and Zoantharia tabulata" (Green's Cœlenterata).

The new Brachiopoda are very few in number, the principal one being the genus Producta, some species of which are quite the largest of all Brachiopodous shells, and make up whole beds in the Carboniferous limestone. Some species (if not all) were covered with long slender spines which have generally been rubbed off after death, but which I have often seen attached to many Productæ in the Carboniferous limestone of Derbyshire, sometimes extending several inches into the surrounding rock.

Brachiopodous shells differ from ordinary bivalves in several very important particulars. Ordinary bivalves or Conchifers respire by means of gills, of which the beard of an oyster is an example, hence De Blainville called them Lamellibranchiata. The Brachiopoda, on the other hand, have no gills, and respire through the mantle, whence De Blainville called them Palliobranchiata. The Conchifera have their shells on each side of the body, as if a man were to enclose himself in two great shields, one attached to each arm, their valves then are called left and right valves. The Brachiopoda, on the other hand, have their shells before and behind like a great breastplate and backplate, and hence their shells are ventral and dorsal. Hence it follows that the shells of the Conchifera are usually equivalve but inequilateral, while the shells of the Brachiopoda are usually equilateral but inequivalve. In the case supposed above, if the two shields enclosing the man were fastened together between his shoulders, the shields would be equal, each enclosing one half of the body, but when measured from a vertical line drawn through the fastening, or hinge, the parts of each

[1] See Explanation sheet 145 of the maps of the Geological Survey of Ireland, where a Lithostrotion is figured by Mr. Wynne, which I measured myself, and found to be 9 feet across.

shield would probably vary in size and form according to the fashion adopted. In the other case, if the fastening of the two shields were on the top of the head, the parts on each side of the mesial line of the body would be probably equal, and similar in form, but the breastplates and backplates might be very unequal in dimensions, according as the proportions of the front or back of the body were slim or aldermanic. The human frame, however, would very feebly express the inequalities often observable in the ventral and dorsal valves of a Brachiopod, since they are often both convex in the same direction, one fitting into the other and leaving but a very slender curved interior for the animal's body. The ventral shell is always the largest, and from a hole in its beak there often proceeds a horny sort of attachment, by which the animal fastened itself to rocks beneath the sea. This in Terebratula (Waldheimia) australis, is not unlike the stalk of an apple, and the shells grow in great clusters beneath overhanging rocks, just under low water, in Sydney harbour, where I have gathered them. Other species are found only in deep water.

Many Brachiopodous shells have curious internal shelly plates, or spikes, or loops, and a large portion of them, if not all, have ciliated arms coiled up, sometimes free, and sometimes attached to these shelly spikes or loops. It is from these arms or brachia they derive their name. In the Spiriferæ these shelly supports of the arms extend throughout the valves, from the hinge to each extremity, coiled in a spiral form like a watch spring. In the Pentamerus, three shelly projecting plates divide the interior of the shell into five parts, whence its name.

Some of the shells, when examined microscopically, are found to be minutely perforated by small canals, while others are destitute of this structure ; all the Terebratulidæ, for instance, are perforated, but none of the Rhynchonellidæ (see Davidson's Introduction, with Carpenter's observations, to *Brachiopoda, Palæontological Society's Volume*, and Woodward's *Manual of the Mollusca*).

The Brachiopoda are numerous in species, but are still more abundant in individuals in all Palæozoic rocks, hundreds of Brachiopodous shells often occurring for one Conchifer.

In the Carboniferous rocks, however, the new genera of Conchifera are much more numerous than the new genera of Brachiopoda, although the species of those genera are comparatively few, and the individuals scarce, compared to those of the Brachiopoda, so far as the limestones of the formation are concerned, while in the shales the Conchifera are often very numerous, especially in the Coal-measures.

The Gasteropoda likewise shew many new genera, several of which still live in our own seas. They, however, as well as all other Palæozoic Gasteropods, belong to the Holostomatous class, or those which have the mouths of their shells unbroken by any indentations. These are all vege-

table feeders, the notches and canals in the mouths of the carnivorous genera serving for the passage of an armed tube used for boring into other shells and feeding on their inhabitants.

The Cephalopoda shew true Nautili of the same genus as those now existing, and differing from the group of Lituites in the earlier periods, in the curve of the shell, which in Lituites is more open, some of the whorls not touching each other. The genus Clymenia, confined apparently to the lower part of the Carboniferous rocks, has its septa slightly waved, and its siphon on the inner margin of the shell instead of the centre. The great genus Orthoceras continues and exhibits two new modifications, while the Goniatite comes in as the harbinger of the Ammonites.

The Echinodermata existed in the most enormous abundance in the form of Crinoids or Sea Lillies, many new genera making their appearance, and beds of solid limestone a thousand feet thick, and hundreds of square miles in extent, seeming to be almost entirely composed of fragments of these creatures. They also shew forms closely allied to the existing Sea-Urchins, although these were as yet rare.

Among the Crustacea, the great group of the Trilobites becomes limited to one or two genera, Griffithides and Phillipsia, and then they disappear in toto, and have never been found in any newer rock. The genus Bellinurus, however, begins to exist in small forms, which prefigure the large Limulus or King Crab of the present day, and other bivalvular Cypris or Cythere-like crustaceans likewise make their appearance together with many species of Dithyrocaris.

Insects also existed, their wing cases and parts of their bodies having been found in the Coal-measures.

Great Fish existed with polished bony scales, and others, like the Port Jackson shark, with pavements of flat teeth over their mouths and gullets, in order to crush and grind shells. Fish teeth and scales are found in great abundance in some places in the Carboniferous rocks, and sometimes their whole skins nearly as perfect as would be the skin of a living fish prepared for a museum; the latter generally occurring in the shale beds or in the ironstones included in them.

We also now get the first indubitable proofs of the existence of Reptiles in the fossils found in some parts of the Continent and North America, although none have yet been met with in the British islands.

Extinction of forms towards the close of this period.—Besides those generic forms which were marked in the list at p. 536 by an asterisk, to shew that they died out towards the close of the period, and have not left any remains, so far as is yet known, in any newer rock, other generic forms which lived in preceding periods now died out and became extinct. Of these the following may be taken as an approximately accurate list:—

Actinozoa, Alveolites, Clisiophyllum, Cyathaxonia, Cyathophyllum, Favosites, Heliolites, Sarcinula, Strephodes, Syringopora, Zaphrentis,* all from the Cambro-Silurian or Silurian periods.

Polyzoa, Polypora, Ptylopora.

Brachiopoda, Athyris, Chonetes, Orthis, Pentamerus, Retzia.

Conchifera, ? Pterinea†, Conocardium, Dolabra, Leptodomus, Sanguinolites.

Gasteropoda, Raphistoma.

Pteropoda, Conularia.

Cephalopoda, Actinoceras, and all the Orthoceratidæ, so far as the British rocks are concerned.

Echinodermata, Actinocrinus, Palæchinus, Poteriocrinus, Rhodocrinus, Taxocrinus.

Annelida, Serpulites.

Crustacea, Cypridina, Dithyrocaris, and the whole order of Trilobites.

Fish, Acanthodes, Asterolepis, Ctenacanthus, Ctenoptychius, Diplopterus, Onchus, Ptycacanthus.

* Except one doubtful species in the Inferior Oolite.

† A species, referred to this genus with doubt, occurs in Carboniferous rocks. If not rightly so referred, the genus became extinct at the close of the Silurian Period.

CHAPTER XXXI.

PERMIAN PERIOD.

In the examination of the great series of British rocks, a large group of reddish-coloured sandstones is met with, lying above the Carboniferous rocks, similar in general aspect to those which lie below them. These red sandstone groups were called the Old and New Red Sandstone. We have seen in the preceding pages that it will be necessary for the future to separate the Old Red Sandstone into two parts—the one forming the upper part of the Lower Palæozoic series; the other forming the base of the Upper Palæozoic series, the intermediate or passage beds between the two being not yet known.

The necessity for separating into two distinct parts the beds previously classed together as New Red Sandstone, was recognised some years ago by Sir R. I. Murchison. This separation has indeed been made so wide as to class the two parts in different epochs, the one forming the uppermost of the Palæozoic, while the other forms the base of the Mesozoic series.

TYPICAL ROCKS.

Russia and Germany.—When Sir R. I. Murchison examined Russia and the Ural Mountains, he found a great series of "grits, sandstones, marls, conglomerates, and limestone, sometimes enclosing great masses of gypsum and rock salt," overlying the Carboniferous rocks, but beneath the Trias, and occupying the district which formed the ancient kingdom of Perm. He proposed, therefore, the name of the Permian rocks for them.

The lower part of this deposit agreed with the red beds which in Germany had received the name of the "rothe-todtliegende," or red dead-layers. These were called "dead" because the copper which was worked in the beds above them died out as they came into these beds below. These lower red beds swell out in the Thuringerwald to a thickness of 4000 feet (*Siluria*, p. 333), though this must be taken as a mere local exception to its general dimensions.

Above this are certain beds of dark shale, with copper ore, hence

called Kupfer Schiefer, and over that a limestone called the Zechstein, which passes up into a red and mettled marl, called the Bunter Schiefer.

The section there is—

4. Bunter Schiefer.
3. Zechstein.
2. Kupfer Schiefer or Mergel.
1. Rothe-todtliegende.

Durham and the North-East of England.—Professor Sedgwick, in his celebrated paper in the third vol. *Trans. Geol. Soc.*, Lond., described the rocks of Durham as follows:*

	Feet.
6. Red gypseous marls . . .	100
5. Thin bedded gray limestone . .	80
4. Red gypseous marls, slightly saliferous .	200
3. Magnesian limestone . . .	500
2. Marl slate	60
1. Lower red sandstone . . .	200

Of these, No. 1 is the same as the rothe-todtliegende; No. 2 is identical with the Kupfer Schiefer, containing many of the same peculiar species of fish; and the beds above may be equally paralleled with the Zechstein and Bunter Schiefer.

1. The Lower Red Sandstone is a very irregular deposit, lying unconformably on the Coal-measures, and in hollows eroded in their surface. Nevertheless it contains plants of the same species as those of the Coal-measures.

2. The Marl slate is a brown indurated fissile shale, with occasional beds of thin compact limestone.

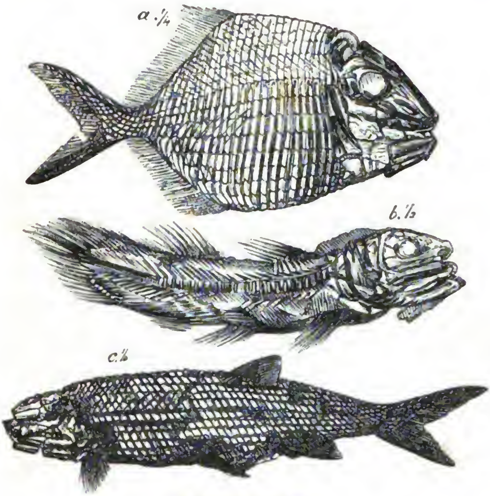
Characteristic Fossils.

Plants, Neuropteris Huttoniana; Caulerpa selaginoides.
Brachiopoda, Lingula Credneri; Discina speluncaria; Productæ and Spirifers.
Fish, Palæoniscus elegans, comptus (Foss. gr. 20, *c*), glaphyrus, etc.; Platysomus macrurus; Acrolepis Sedgwickii; Pygopterus mandibularis, etc.; Cœlacanthus granulosus (Foss. gr. 20, *b*).

3. The Magnesian limestone is a singularly diversified mass of limestones, sometimes compact, at others crystalline, brecciated, earthy, globular, oolitic, cellular, etc.; some beds like piles of cannon or mus-

* See also an excellent paper on the Permian rocks of South Yorkshire, by Mr. Kirby, Quarterly Journal Geological Society, vol. xvii.

ket balls, others like bunches of grapes, etc.; some very hard, some quite friable, some thin and flexible. General colour shades of yellow, sometimes red and brown.



Fossil Group No. 20.
Permian Fish.
a. Platysomus striatus. *b.* Cœlacanthus granulosus. *c.* Palæoniscus comptus.

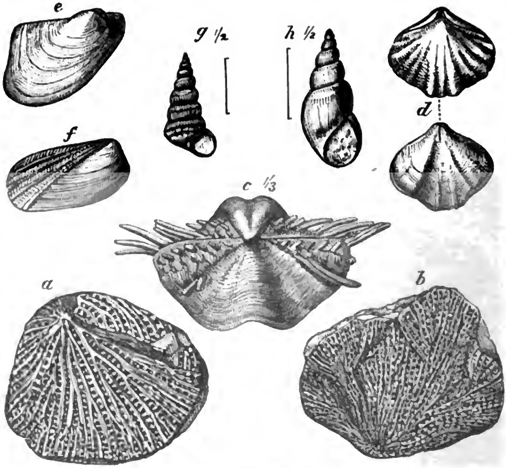
Its characteristic fossils are numerous, the following being a selected list :—

Plants.	
Voltzia Phillipsii	Lind. Foss. flo. 195.
Actinozoa.	
Polycœlia profunda	Pal. Soc. King. and Ed.
Polyzoa.	
Fenestrella retiformis	Foss. gr. 21, *b.*
Synocladia virgulacea	Foss. gr. 21, *a.*
Thamniscus dubius	King. Per. foss.
Brachiopoda.	
Camarophoria Schlotheimi . . .	Foss. gr. 21, *d.*
Producta horrida	Foss. gr. 21, *c.*

Spirifera cristata	* King. Per. foss.
Strophalosia Goldfussii	*Ibid.*

Conchifera.

Avicula speluncaria	*Ibid.*
Axinus obscurus	*Ibid.*
—— truncatus	*Ibid.*
Bakevellia antiqua	Foss. gr. 21, *e.*
Cardiomorpha modioliformis . . .	King. Per. foss.
Pleurophorus costatus	Foss. gr. 21, *f.*
Schizodus Schlotheimi	King. Per. foss.



Fossil Group No. 21.

Permian Fossils.

a. Synocladia virgulacea.
b. Fenestrella retiformis.
c. Producta horrida.
d. Camarophoria Schlotheimi.
e. Bakevellia antiqua.
f. Pleurophorus costatus.
g. Loxonema fasciatum.
h. Macrocheilus symmetricus.

Gasteropoda.

Euomphalus Permianus . . .	King. Per. foss.
Loxonema fasciatum	Foss. gr. 21, *g.*
Macrocheilus symmetricus . . .	Foss. gr. 21, *h.*

* King's Permian Fossils, Pal. Soc. vol.

Natica Leibnitziana	King. Per. foss.
Pleurotomaria antrina	*Ibid.*

Cephalopoda.

Nautilus Bowerbankianus . . .	*Ibid.*
——— Freieslebeni	*Ibid.*

Fish.

Platysomus striatus	Foss. gr. 20, *a.*

Midland counties of England.—The magnesian and other limestones of the Durham section die away towards the south, and finally disappear near Nottingham.

There are, however, in Warwick, Stafford, Shropshire, and Cheshire, a great series of beds, occupying the same relative position between the Coal-measures and the Trias, or New Red Sandstone proper, as may be seen from the section in fig. 117, which exhibits the whole series of beds which in that country intervene between the top of the Coal-measures and the base of the Lias.

The diagram is constructed partly from sheet 23 of the Horizontal Section of the Geological Survey. The parts belonging to the Permian group are those called *b* and *c*.

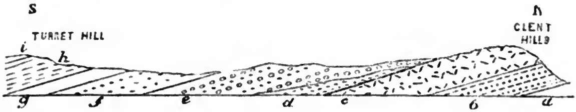


Fig. 117.

Diagrammatic section across the Clent Hills, 900 feet high, from the south end of the South Staffordshire coal-field to the Lias of Worcestershire.

			Feet.
Oolitic.—*i.* Lias—			
New Red Sandstone.	Keuper.	*h.* Red marls, with salt and gypsum	500
		g. Waterstones, white freestone with thin brown sandstone and marl	200
	Bunter.	*f.* Soft red and brown mottled sandstone	500
		e. Pebble beds, uncompacted conglomerate of pebbles of quartz rock, varying from 150 to	300
		d. Soft brick bed sandstone, varying from 0 to . . .	550
Permian.		*c.* Trappean breccia	450
		b. Red marls and sandstones, with thick cornstone bands .	400
Carboniferous.—*a.* Coal-measures.			

The marls in group *b* are often remarkable for their deep blood-red character, and some of the sandstones are likewise dark red. The

cornstones are quite like those of the Old Red Sandstone, and were at one time believed to belong to it; one of the earliest descriptions of the cornstone of the Old Red Sandstone being taken in fact from these beds.

The Trappean breccia *c* consists in some parts so entirely of loose angular fragments of a porphyritic trap that it was believed to be merely the superficial debris derived from the solid trap rock beneath. In other parts, however, it contains square slabs and angular fragments of Llandovery sandstone, and other fragments, so that Professor Ramsay believes that some of them must have been transported by ice. (*Quarterly Journal of the Geological Society*, vol. ii., p. 185, and *Mems. Geol. South Staffordshire Coalfield*, 2d Edition.)

Ireland and Scotland.—The red sandstones of Roan Hill, near Dungannon, containing abundance of Palæoniscus catopterus, are probably Permian. Yellow magnesian limestones, exactly like those of Durham, and with many of the characteristic fossils previously mentioned, occur in patches at Ardtrea,* county Tyrone, and blocks of it have been found at Cultra, near Belfast.

The red sandstones of Dumfries, with tracks of reptiles so beautifully figured by Sir W. Jardine in his "Ichnology of Annandale," may also possibly belong either wholly or in part to the Permian rather than the Triassic Period.

Life of the Period.

Our evidence as to the life of this period is very scanty. Some of the vegetation of the Carboniferous Period seems to have been still existing during the early part of the Permian; but to have been replaced by other forms during the latter part. This alone would lead one to suspect the passage of a vast interval of time as yet unaccounted for.

In the animal kingdom the genera Fenestrella and Producta, and several genera of fish which are common in earlier Palæozoic rocks still existed. Labyrinthodont reptiles, also, of which indications appeared in the upper rocks of the Carboniferous Period, existed during the Permian, and into the next (or Triassic period), when they became perhaps most abundant.

There are not many new forms of life that date from the Permian Period; but this may be because of the very defective state of the records of it which have come down to us, or, in other words, because the fossiliferous groups of Permian rock we yet know are few and far between.

The following list contains all that could be named:—

* See Professor King's paper (*Dublin Nat. Hist. Review*, No. x.), or *Journal of the Geological Society, Dublin*, vol. vii.

Plants, * Caulerpites, Confervites, Voltzia.
Spongidæ, * Bothroconis, * Mammillopora.
Foraminifera, Dentalina, Spirillina, Textularia.
Actinozoa, * Polycælia.
Polyzoa, * Synocladia, * Thamniscus.
Brachiopoda, None.
Conchifera, * Bakewellia, ? Lima, * Schizodus (part of Axinus).
Gasteropoda, ? Rissoa.
Annelida, Vermilia.
Fish, * Acrolepis, * Gyropristis.
Reptiles, Labyrinthodon, * Palæosaurus, Thecodontosaurus, ? Ichnites of Corncockle Moor, etc.

In addition to the genera marked with an asterisk, as having both commenced and ended their existence in this period, the following, which date from earlier times, appear now to have become extinct :—

Plants, Neuropteris, Sigillaria, and Stigmaria.
Actinozoa,[1] Chætetes, Fistulipora.
Polyzoa, Fenestrella, Glauconome.
Brachiopoda, Camarophoria, Orthisina, Producta.
Conchifera, Axinus, Myalina, Solemya.
Echinodermata, Cyathocrinus, Archæocidaris.
Crustacea, Ceratiocaris.
Fish, Cœlacanthus, Gyracanthus, Palæoniscus, Platysomus, Pygopterus.

Gaps in the Palæozoic Series.

It will be useful, perhaps, if we just pause for an instant to note the gaps or breaks in the succession of rocks hitherto described, or those parts where there seem to be beds wanting in different parts of it.

In Ireland there is a distinct break between the Cambrian and the Cambro-Silurian rocks, so that the upper part of the one and the base of the other are both wanting. It is possible, perhaps, that this deficiency is completely supplied by the Lingula flags of North Wales. At the same time this is by no means certain and one or more intermediate groups or formations may yet be discovered in other parts of the world.

There is also a distinct break between the Cambro-Silurian and upper Silurian rocks. Elevation and denudation were both taking place during the deposition of the Llandovery rocks. Dry land was formed where sea prevailed before, and where subsequent depression allowed it

[1] All the Permian Corals known belong to Rugosa and Zoantharia tabulata; but the order Rugosa now disappears with the exception of one single species (Holocystis elegans), which is found in the Greensand of the Cretaceous Period (*Greene's Manual of Cœlenterata*).

to spread afterwards, as shewn by Edward Forbes and Professor Ramsay in the Longmynd country.

When we reach what is called the Devonian Period we have the clearest evidence of an enormous break in the series. The utter discordance in Scotland of the upper part of the Old Red Sandstone, on what Mr. Geikie still calls the lower Old Red Sandstone, the similar discordance of the Old Red Sandstone proper on the Dingle beds of Ireland, the concealed but still existing discordance of the corresponding groups in the district of Siluria, prove this gap.

The impossibility of pointing to any place where there is to be seen a regular succession of beds from true upper Silurian through the Devon and Eifel limestones into the Carboniferous series, is evidence in favour of the same fact. The change in the forms of life between the Upper Silurian and Lowest Carboniferous, only partially and obscurely accounted for in the fossils of the Devonian slates and limestones, corroborates it.

It is possible that some of the rocks of North America fill up a portion of this great gap.

The great Carboniferous formation as developed in the British islands is perhaps the best example we have in the world of a continuous series, but when we come to the Permian groups, and the Triassic immediately above them, continuity of deposition is evidently the exception rather than the rule. Elevation and disturbance prevailed then as it did in the interval between the Upper Silurian and Carboniferous formations, and even to a still greater extent. Much dry land was probably formed, vast denudation took place by the slow process of the waste of coasts and the atmospheric degradation of exposed countries in both these vast intervals, and the rocks at present known to us are chiefly the results of this waste, detritus deposited here and there in local patches, or a few still more local remnants of the intervals of tranquil deposition in the lakes or on the sea bottoms of the periods.

The Cambro-Silurian, the Upper Silurian, and the Carboniferous, may be taken as three tolerably complete and consecutive groups of rock, three isolated volumes of our history. The Cambrian and Pre-Cambrian records are difficult to decipher. The Llandovery, the Devonian, and the Permian records, are but a few torn and half obliterated leaves from lost volumes that may perhaps never be recovered.

SECONDARY, OR MESOZOIC EPOCH.

CHAPTER XXXII.

TRIASSIC OR NEW RED SANDSTONE PERIOD.

THE term Trias is a continental one, as in Germany and the borders of France the rocks deposited during this period formed three well marked groups. The contemporaneous rocks in Britain were called New Red Sandstone, under which term, however, were included at one time those that have just been described as Permian.

It will be best to look to the Continent, in the first instance, as containing the most typical series of rocks of this period.

TYPICAL GROUPS OF ROCK.—*Germany*—

	Feet.
3. Keuper . . .	1000
2. Muschelkalk . .	600
1. Bunter Sandstein .	1500

1. The Bunter Sandstein, or "variegated sandstone," is a red and white sandstone interstratified with red marls and thin bands of limestone, sometimes oolitic, sometimes magnesian. This is the "Grès bigarré" of the French.

Characteristic Fossils.

Plants, Thirty species have been found near Strasburg ; Ferns, Cycads, and Conifera. Among them are Calamites Mougerti, Equisetites, Æthophyllum speciosum and stipulare, Neuropteris elegans, Voltzia heterophylla, Albertia elliptica, Anomopteris.

Fish, Acrodus Braunii, Placodus impressus.

Reptiles, Trematosaurus, Nothosaurus Schimperi, footprints of Labyrinthodon.—(*Vogt's Lehrbuch*, vol. i. p. 383).

2. Muschelkalk. A compact reddish gray, or yellowish limestone, rarely oolitic, but in some places magnesian, especially in the lower beds, which include beds of gypsum and rock salt. It might accordingly be divided into two sub-groups—

b. Upper Muschelkalk, regularly bedded limestone, more than 300 feet thick.

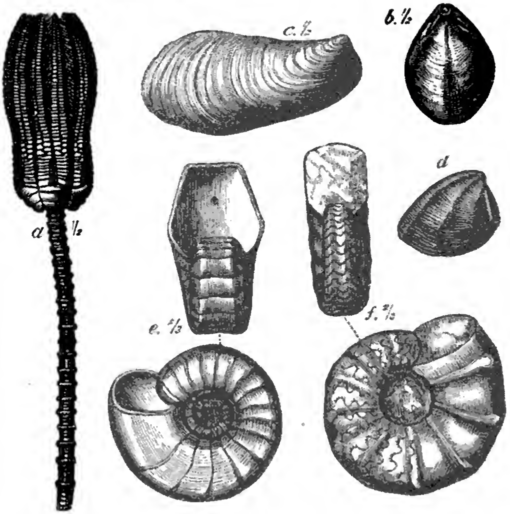
a. Alternations of limestone, dolomite, marl, and gypsum or anhydrite and rock salt, 280 feet.

Characteristic Fossils.

Brachiopoda, Terebratula vulgaris, Foss. gr. 22, *b.*

Conchifera, Gervilia socialis ; Lima striata ; Myophoria vulgaris, Foss. gr. 22, *d* ; Ostrea placunoides and Schubleri ; Pecten discites, P. lævigatus.

Gasteropoda, Turritella reallata.



Fossil Group No. 22.
Muschelkalk Fossils.

a. Encrinus lilliformis.
b. Terebratula vulgaris.
c. Avicula (Gervilia) socialis.
d. Myophoria vulgaris.
e. Nautilus hexagonalis or bidorsalis.
f. Ceratites nodosus.

Cephalopoda, Ceratites nodosus, Foss. gr. 22, *f* ; Nautilus hexagonalis, Foss. gr. 22, *e* ; N. hirundo.

Echinodermata, Encrinus lilliformis, Foss. gr. 22, *a* ; Ophiura prisca, O. scutellata.

Fish, Acrodus Gaillardoti ; Ceratodus heteromorphus ; Hybodus Mougeoti and major ; Pemphix Suensi ; Saurichthys apicalis and costatus.
Repiles, Nothosaurus ; Simosaurus.—(*Vogt*).

3. Keuper. Marnes irisées of the French. Principally red and green marl, but is locally divisible into three sub-groups, namely :—

c. Keuper sandstone of a yellowish white, sometimes green and reddish colour, containing Calamites and other plants.
b. Keuper marls, with gypsum and dolomite, containing Coprolites, Fish, and Saurian bones, scales, and teeth.
a. Lettenkohle (clay coal) group, a dark gray shale or gray sandstone, containing small irregular beds of impure earthy coal, with remains of Mastodonsaurus (Labyrinthodon), Gervillia, Lingula, and Estheria.

This latter group rests directly on the Muschelkalk, and seems, from its animal remains, to belong to it, but its plants are those of the Keuper.

Characteristic Fossils of the Keuper.

Plants, Calamites arenaceus ; Equisetites ; Pterophyllum Jaegeri, and Munsteri ; Nilsonia.
Crustacea, Estheria minuta.
Reptiles, Mastodonsaurus (Labyrinthodon), Capitosaurus.
Mammal, Microlestes antiquus.

Near Stuttgart, and in other parts of Germany, the Keuper sandstone is capped by a layer of sandstone breccia, full of the remains of Saurians and Fish in fragments, exactly like that known in England as the " bone bed."

In the Supplement of Sir C. Lyell's Manual, published in 1857, there are described a number of beds which contain a mixture of fossil forms belonging to Palæozoic and Mesozoic types.

Near Hallstatt (south-east of Salzburg), on the north side of the Austrian Alps, and at St. Cassian on the south side, are a set of beds composed of red, pink, and white marble, from 800 to 1000 feet in thickness, and containing more than 800 species of fossils.

These species are mostly peculiar to the Hallstatt and St. Cassian beds, but they belong to genera, some of which are only to be found elsewhere in beds belonging to the Palæozoic rocks, while others are equally confined to beds of Mesozoic age, as is shewn in the following table :—

Palæozoic Genera.	Triassic Genera.	Mesozoic Genera.
Cyrtoceras.	Ceratites.	Ammonites.
Orthoceras.	Scoliostoma.	Belemnites.
Goniatites.	Naticella.	Nerinæa.
Loxonema.	Platystoma.	Opis.
Holopella.	Isoarca.	Cardita.
Murchisonia.	Pleurophorus.	Trigonia.
Euomphalus.	Myophoria.	Myoconchus.
Porcellia.	Monotis.	Ostræa.
Megalodon.	Koninckia.	Plicatula.
Cyrtia.		Thecidium.

"The first column marks the last appearance of several genera which are characteristic of Palæozoic strata. The second shews those genera which are characteristic of the Upper Trias, either as peculiar to it or as reaching their maximum of development at this era. The third column marks the first appearance of genera destined to become more abundant in later ages."—(*Lyell's Supplement.*)

Underneath the Hallstatt and St. Cassian beds are others called the Guttenstein and Werfen beds, containing *Ceratites cassianus*, *Myacites fassaensis*, *Naticella costata*, etc. They consist of—

	Feet.
b. Guttenstein beds, black and gray limestone, alternating with red and green shale . . .	150
a. Werfen beds, red and green shale and sandstone, with gypsum and rock salt.	

It is yet doubtful whether these are only a lower portion of the St. Cassian beds, or are to be considered as equivalents of the Lower Trias.

Over the St. Cassian beds again come 2000 feet of white or grayish limestone, known as the Dachstein beds, and above these 50 feet of gray and black limestone with calcareous marls, called the Kœssen beds, or Upper St. Cassian, by M.M. Escher and Merian. Each of these groups contains a peculiar set of fossils of a character which renders it uncertain whether they should be classed as Upper Triassic or as Lower Liassic groups.

The Dachstein beds are unfossiliferous below, but the upper portion contains beds entirely made up of Corals (Lithostrotion), and others, containing Hemicardium Wulferi, Megalodon triqueter, and other large bivalves.

The Kœssen beds contain as characteristic fossils, Avicula contorta and inæquivalvis, Pecten Valoniensis, Cardium Rheticum, Spirifera Munsteri, together with many Brachiopoda, some peculiar, a few found in the Lias. "According to Mr. Suess, the Kœssen beds correspond to the upper bone bed of Swabia."—(*Lyell's Supplement*).

It appears most probable that we may class these formations as follows :—

Keuper.	Kœssen or Upper St. Cassian beds.
	Dachstein beds.
Bunter.	Hallstadt and St. Cassian beds.
	Guttenstein beds.
	Werfen beds.

How far the beds may be continuous, or what gaps may be unrepresented among them, remains doubtful. It is possible the Muschelkalk should be intercalated between two of them, and that all these may be merely a few isolated fragments of the series that might have been deposited during a vast imperfectly represented interval.

Great Britain.—In our own country it is certain that the series is hereabouts very imperfect. The beds we have, however, are the following :—

		Feet.
Keuper.	5. Red marls, with rock salt and gypsum .	1000
	4. White and brown sandstones, with beds of red marl (Waterstones) . .	300
Bunter.	3. Upper red and mottled sandstone . .	500
	2. Pebble beds or uncompacted conglomerates	500
	1. Lower red and mottled sandstone . .	250

The thicknesses given above are the maxima ever supposed to be attained by the several groups, those maxima never existing together in any one place, so that the average maximum thickness of the whole does not probably exceed 1000 or 1500 feet.

The "Bunter" sandstones are generally soft, "brick-red," thick-bedded sandstones, with much oblique lamination, and occasional thin bands of clay or marl. Green or white blotches occur here and there.

Thick beds of quartzose gravel occur in it frequently, sometimes compacted into a regular conglomerate, but often loose and incoherent, so as to appear like "drift" (*Mems. G. S.*, South Staff. coal-field). These "pebble beds" occur about the middle of the group, but sometimes form its base, to the exclusion of any part of No. 1. Like all conglomerates, they are very capricious in their occurrence, setting in and ending quite suddenly. Beds of marl are sometimes associated with them.

The "Keuper" beds have almost invariably the "waterstone" subdivision at their base, often containing beds of white sandstone, which are used for building stone.

The red clays or marls above these contain frequently beds of gypsum, and sometimes beds of rock salt, which are often as much as 80 or 100 feet in thickness. These are worked largely in the centre of Cheshire, and have also been pierced at Duncrae, near Carrickfergus, in county Antrim. The brine springs of Droitwich in Worcestershire, of Shirleywych in Staffordshire, and other places, are derived from such beds. In Cheshire, near Northwich, the following section shews a part of the thickness of these beds :—

	Feet.
Upper strata (marl, etc.)	127
1st bed of rock salt	85
Indurated marl (locally called stone) . .	30
2d bed of rock salt	106
Indurated marls, with thin beds of salt . .	151
	499

Over this thickness of 500 feet, are other beds of marl, etc., before we reach the base of the Lias, and, under it, are other marls, so that the entire depth of this group must be 700 feet with, or 500 without, the salt.—(*Ormerod on Cheshire*, *Geological Journal*, vol. iv.)

Section, fig. 117, p. 545, deduced from the maps and sections of the Geological Survey, shews these beds as they occur in north Worcestershire, to the southward of the South Staffordshire coalfield. They rest here upon the Permian trappean conglomerates *b*, and after dipping gently to the south for some miles, are finally covered by the base of the Lias *i*. In this section the pebble beds of the Bunter *e* rest directly on the Permian *c*, but a subdivision *d*, is introduced beneath them, to represent the Lower Soft red sandstone ; as in north Staffordshire, it occurs with a thickness of 500 feet, as shewn in sheet 54 of the Hor. Sec. G. S. It is, however, quite possible that these variations are simply the result of the absence of pebbles in one locality, and their presence in another, in the same beds of sand.

Ireland.—The section in Ireland is as follows :—

	Feet.
Red marls, with gypsum	500
Red salt	22
Marl and salt	26
Pure rock salt	84
Mixed rock salt	14
Pure rock salt	39
Blue bands and freestone, etc.	25
	700

(*See paper by Mr. J. B. Doyle, in J. Geol. Soc., Dub.*, vol. v.)

These have other beds of red marl above them, about 100 or 150 feet thick, over which is the base of the Lias.

Underneath these red marl beds of the valley of the Lagan occur red sandstones belonging to the Bunter series, which have been sunk into, near Lisburn, in search of water, for a depth of over 500 feet, without reaching their base.—(*See section, fig.* 122.)

Avicula Contorta Zone, or Rhætic Beds.—Dr. Wright of Cheltenham has lately described (*Q. J. Geol. Soc.*, vol. xvi.) as the uppermost part of the Keuper some beds in the south of England that had hitherto been classed with the Lias. They are perhaps properly intermediate between the two, and are certainly contemporaneous with the "Kössener schichten" of Guep (or Upper St. Cassian of Escher and Merian). They may be well seen at Garden Cliff, on the Severn, near Westbury, where, above the red and gray shales of the ordinary red marl series, there is a set of black and dark gray shales about 35 feet thick, containing the Bone bed, 1 inch thick, and capped by the gray Lias limestone. They may be seen also at other places in the neighbourhood, and in Warwickshire and Staffordshire, in which latter locality (north of Abbotts Bromley) they were visited by myself, and described as Lias in the year 1849, and afterwards mapped by my colleague Mr. Howell.

These beds are also represented in the north of Ireland at Lisnagrib and Derrymore, by dark shales and grits, with some of the characteristic fossils of the group.—(General Portlock's *Report on Londonderry*, etc., p. 105.)

Characteristic Fossils.—Very few fossils have been found in any part of the New Red Sandstone of the British islands. Tracks, however, of several kinds of reptile have been found—among others, those of the one formerly called Cheirotherium, from the likeness of its foot to the human hand, but since named Labyrinthodon, from the structure of its tooth. These impressions have been met with also, I believe, in Permian sandstones.

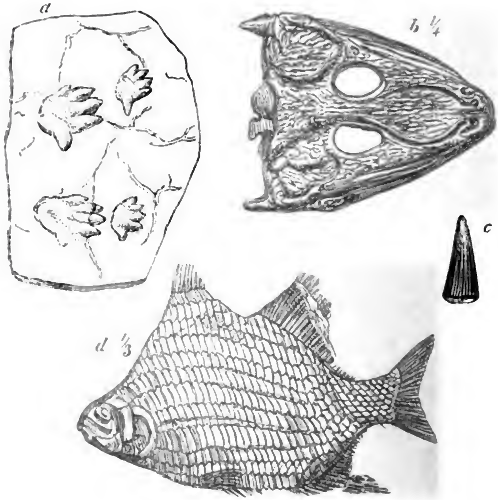
Fig. *a* in the Fossil Group 23, is a reduced representation of these foot-tracks, *b* and *c* being the skull and tooth of the animal supposed to have caused them. Other tracks were exhibited from some of the sandstones of Staffordshire, by the Rev. W. Lister of Bushbury, at the meeting of the British Association at Oxford in 1860.

Fragments of fossil wood are often found in the sandstones, interstratified with the red marls of the Keuper, and the fossil fish figured in Foss. gr. 23, *d*, was procured from the same beds, and described by Sir P. Egerton in *Q. J. Geol. Soc.*, vol. x. Hybodus Keuperinus also may be mentioned as found in these beds, and the teeth of the mammalian *Microlestes*, near Frome, by Mr. C. Moore.

The following fossils are characteristic of the Rhætic beds (see also Mr. C. Moore's paper on these beds, in Q. J. G. S., vol. xvii.)

Conchifera.

Avicula contorta	Port. G. R., t. 25, A.
Cardium Rhæticum . . .	?Phill. G. Y., t. 11, fig. 7.
Modiola minima	Sow. M. C., 210.
Monotis decussata . . .	Goldfuss.
Ostræa liassica.	
Pecten Valoniensis. . . .	Port. G. R., t. 25, A.



Fossil Group No. 23.

Triassic Fossils.

a. Footprints of Labyrinthodon giganteum.
b. Head of Labyrinthodon giganteum.
c. Tooth of Labyrinthodon giganteum.
d. Dipteronotus cyphus.

Crustacea.

Estheria minuta	Geol. Tr., vol. v., t. 28.

Fish.

Acrodus acutus and minimus . .	Agassiz.
Ceratodus altus, and five others .	

Hybodus minor, and four others .	Agassiz.
Nemacanthus monilifer . . .	
Saurichthys apicalis . . .	

Lie and Position of the New Red Sandstone of the British Islands.—The red rocks just described rest quite unconformably and indiscriminately upon all or any of the groups of rocks mentioned in the previous chapters. The Palæozoic rocks of the British Islands had been tilted, contorted, and fractured, in varions directions, and had suffered repeatedly and enormously from denudation before the deposition of the New Red Sandstone. The broken and varied surface which the Palæozoic rocks generally possess had been produced on them, either completely or very approximately, before this time. The New Red Sandstone reposes upon this surface usually in a horizontal or slightly inclined position, thickly where that old surface is deeply buried, more thinly as it rises towards the present surface of the ground. Where the Palæozoic rocks rise out of it into hills or mountains, the New Red Sandstone sweeps round their margin with a flat or gently undulating surface. In many cases the New Red Sandstone ends abruptly against the Palæozoic ground, either from having been deposited against a cliff of the older rocks, or from its having been made to abut against them by subsequent large faults and dislocations.

The New Red Sandstone thus surrounds the great Pennine chain of the north of England, from Lancashire through Cheshire into Shropshire, Staffordshire, Leicestershire, and Nottinghamshire, and runs down the vale of York to the coasts of Durham. It bounds, in the same way, the Palæozoic rocks of Wales from the mouth of the Dee to that of the Severn, and runs thence through Somerset and Devon to the mouth of the Exe.

If we draw a slightly sinuous line from the mouth of the Tees through the centre of England to the mouth of the Exe, we should, as remarked by Dr. Buckland in his Bridgewater Treatise, divide England into two totally dissimilar parts, in which the form and aspect of the ground, and the condition and employments of the people, were alike contrasted with each other. The part to the north-west of this line is chiefly Palæozoic ground, often wild, barren, and mountainous, but in many places full of mineral wealth ; the part to the south-east of it is Secondary and Tertiary ground, and generally soft and gentle in outline, with little or no wealth beneath the soil. The mining and manufacturing populations are to be found in the first district, the working people of the latter are chiefly agriculturists.

In Ireland the lie and position of the New Red Sandstone is very interesting and characteristic. If the reader will place before him the north-east part of Sir R. Griffith's excellent geological map of Ireland,

he will see that the New Red Sandstone is confined to the county Antrim and its immediate borders. If he will follow with his eye the boundary of the formation, he will see all the Palæozoic rocks coming out from underneath it in different places. The Metamorphic and Granitic rocks, partly covered by Old Red Sandstone, rise from under it in Londonderry, striking north-east and south-west, that strike being continued beneath the New Red, as appears by the occurrence of the same rocks in the north-east corner of Antrim, near Cushendall, where the upper rocks have been subsequently removed from them.

Farther south, about Dungannon, different portions of the Carboniferous rocks come to the surface from beneath the New Red covering, while along the south-east side of the valley of the Lagan we find the dark slates and grits of the Lower Silurian formation rising from beneath it. Just on the south-east side of Belfast Lough, however, between Cultra and Holywood, the lowest of the Carboniferous rocks appear, resting unconformably on the Lower Silurians, but dipping at a high angle to the north-west beneath the waters of the Lough.

On the opposite shore the New Red and superior beds lie as shewn in the section, fig. 122, in a nearly horizontal position, and no place is known where the Secondary beds lie for any distance in any other position. From these facts it is clear that the New Red Sandstone of the north-east of Ireland rests as a great flat cake upon the old surface of the Palæozoic rocks, the beds of which lie beneath that surface in a similarly contorted and greatly denuded condition to that in which they are found outside the New Red Sandstone. The New Red Sandstone itself was formerly more extensive than it is now, covering, in horizontal sheets, much of the country outside its present boundary; and did that old extension now exist, and if pits were sunk through it, it is plain that they could come down on to Silurian beds at one place, on to Mica Schist or Granite at another, on to Old Red Sandstone or Carboniferous Limestone in other places, and only in one or two small localities would Coal-measures be met with.

What would have been true of the extension of the New Red Sandstone, had it been left undenuded, is true now of the part that remains. The section in fig. 122 shews in its lower part the undulating beds and the old surface of denudation of the Palæozoic rocks beneath the horizontal beds of the New Red Sandstone. If a shaft were anywhere sunk through these horizontal beds down to that old surface, it is impossible to say, with any hope of correctness, what Palæozoic rock would be the one met with beneath that surface, in that locality. It might happen to be a little basin of Coal-measures, and if so, there is a possibility of these Coal-measures containing beds of coal, but there is also a possibility of their being Coal-measures without coal. There would, however, be at least an equal chance that

the rock found below the old Palæozoic surface should be any one of the other Palæozoic rocks above enumerated, namely—1, The Carboniferous limestone; 2, the Lower Limestone shale; 3, the Old Red Sandstone; 4, the Lower Silurian rocks unaltered; or, 5, the Mica Schist of Londonderry, which is probably a metamorphosed Lower Silurian rock. The chances, then, would be at least six to one[1] against the probability of Coal-measures with coal being found beneath the part in which the shaft was sunk.

The great practical importance of studying the unconformability of the New Red Sandstone on the Palæozoic rocks below it, and the vast denudation which these rocks suffered before the New Red Sandstone was deposited, cannot be too strongly impressed on the mind of the student. It is one of the chief points in the practical applications of Geology in the British Islands, both for the purpose of guarding against a wasteful expenditure of money in rash enterprises, and for directing it where enterprise may have a chance of being successful.

Life of the Period.

It will be obvious from what has been said of the broken and imperfect character of the rock groups that are known to have been formed in this period, that our knowledge of its forms of life must be very imperfect. This knowledge, however, is still more imperfect, in consequence of the nature of these rocks, which are chiefly red sandstones and marls, the red colour being due to the presence of peroxide of iron, which seems to have been always ill-adapted to the preservation of organic remains.

We may mention the following genera, as among those which apparently made their first appearance during the period, those marked with an asterisk being confined to it.

Plants, Æthophyllum, Albertia, Anomopteris, Dictyophyllum, Pterophyllum.

Brachiopoda, *Koninckia, Thecidium.

Conchifera, Gervillia, *Isoarca, Myoconchus, *Myophoria, Opis, Ostræa, Plicatula, Trigonia.

Gasteropoda, Naticella, Nerinæa, *Platystoma, *Scoliostoma.

Cephalopoda, Ammonites, Belemnites, *Ceratites.

Echinodermata, *Encrinus, Ophiura.

Fish, Acrodus, *Ceratodus, *Dipteronotus, Hybodus, *Saurichthys.

[1] This, of course, would not hold good for the New Red ground close to and in the strike of the little Coal Island Coalfield, while the odds against coal would be still higher towards Portadown, on the one side, or Moneymore on the other.

Reptiles, *Cladyodon, *Dicynodon, ? *Labyrinthodon, *Nothosaurus, *Rhynchosaurus.
Birds, Tracks of, in America.
Mammals, *Microlestes.

Even of those above mentioned, many only appear in the Hallstadt and St. Cassian beds, as, for instance, Thecideum, Ostræa, Plicatula, Trigonia, Ammonites, and Belemnites, which in our own region do not occur in rocks of an earlier date than those of the Oolitic period.

The Cephalopodous genus, Ceratites, which is abundant in the Muschelkalk, forms a remarkable link between the palæozoic Goniatites and the mesozoic Ammonites. The echinoderm Encrinus or typical sea lilly, is also a Muschelkalk genus.

Of the Fish, all except Dipteronotus have been found only in the Bone bed, as to which there is still some dispute whether it be really Triassic or Liassic.

Of the Reptiles, the Cladyodon and Rhynchosaurus, from the Keuper marls and sandstones of Warwick and Shropshires, are allied to Palæosaurus, and shew some analogy to the Dicynodon which comes from the Cape of Good Hope colony, whence it was brought by Mr. Bain. Dicynodon had two great canine tusks (whence its name), and was a fresh-water reptile intermediate between the crocodile, the tortoise, and the lizard. The Labyrinthodonts, of which many synonyms have been proposed in Germany (such as Capitosaurus, Mastodonsaurus and Trematosaurus), were reptiles "having the essential bony characters of the modern *Batrachia*, but combining those with other bony characters of crocodiles, lizards, and ganoid fishes, and exhibiting all under a bulk which, as made manifest by the fossils and footprints, rivalled that of the largest crocodiles of the present day."—(*Owen's Palæontology*). Nothosaurus, with other allied genera, viz., Conchiosaurus, Placodus, Pistosaurus, Simosaurus, Sphenosaurus, Tanystropheus, all come from the Muschelkalk and associated beds on the Continent. They are placed by Owen in the same order with the Plesiosaurus, which came into existence during the next period.

Birds appear to have existed now, though the only evidence for it is found in certain great tracks in the sandstones of the Connecticut river in North America. Some of these footprints, which are undoubtedly those of birds, are 20 inches long, and 4½ feet apart. They occur by thousands over a space 80 miles across, and through a thickness of rock of more than 1000 feet (*Lyell's Manual*). These sandstones are now believed to be of the same period as the Keuper of Germany.

From this same Keuper, both near Stutgardt and near Frome in Somerset, small mammalian teeth have been procured ; Mr. C. Moore being the discoverer of the latter. They are said by Owen to have been

most probably the teeth of a small marsupial insectivorous animal something like the living Myrmecobius of Australia.

After the close of the Triassic period, the following genera dating from earlier times become quite extinct.*

Brachiopoda, Cyrtia, S ; Strophalosia, C.
Conchifera, Megalodon, D ; Pleurophorus, C.
Gasteropoda, Euomphalus, S ; Holopella, S ; Loxonema, S ; Murchisonia, S.
Pteropoda, Bellerophon (Porcellia), S.
Cephalopoda, Cyrtoceras, S ; Goniatites, C ; Orthoceras, S.
Reptiles,—The Labyrinthodont order, P (supposing this to have been in existence in the Permian period).

Most of the genera just mentioned, indeed, would, if they had not been found in the St. Cassian beds, have been taken as extinct at the close of the Palæozoic epoch, as will be seen by reference to the first column of the table on p. 552.

* The capital leters after these genera denote the periods from which they date,—S standing for Silurian, D for Devonian, C for Carboniferous, and P for Permian.

CHAPTER XXXIII.

OOLITIC OR JURASSIC PERIOD.

THE rocks deposited during this period over the area now occupied by the British islands were called Oolitic, because in the part where they were first examined and described by Dr. W. Smith, they contained many beds of oolitic limestone. On the Continent they are called Jurassic, because they compose that chain of mountainous hills sweeping round the north-west frontier of Switzerland, which is known by the name of the Jura. As in other cases, we use the designations applied to those two groups of rock as the name also of the period during which they were deposited.

TYPICAL GROUPS OF ROCK.

South of England.—It has been shewn in section fig. 117 that the upper beds of the New Red Sandstone pass underneath some other beds which were called Lias. The red marls of Cheshire and those in the centre of Staffordshire are capped by isolated patches of these beds. Those of county Antrim are similarly covered.

If we followed the slightly sinuous line mentioned in the last chapter as running from the mouth of the Tees to that of the Exe, we should find wherever the rocks were exposed that the red marls of the New Red Sandstone dipped gently to the east or south-east, and were in that direction covered by beds of dark clay or shale forming the base of the Lias.

Fig. 118 is a diagrammatic representation of a section through the Oolitic series as it occurs in Gloucestershire, in the neighbourhood of Cheltenham and the Cotteswold Hills. It is based on sheet 59 of the Hor. Sec. of the G. S., drawn by Mr. Hull, and sheet 14 drawn by Professor Ramsay and Mr. Bristow.

The thicknesses of these different groups are the maximum thicknesses attained in different parts of the section (No. 59) above mentioned; some variations taking place within the limits of that section itself, which is more than thirty miles long, and still greater changes occurring in other districts.

Fig. 119 is a diagrammatic section based on sheets 20 and 56 of the Horizontal Section of the Geological Survey, both drawn by Mr. Bristow, across parts of Dorsetshire, through the headlands of Portland and Purbeck.

It shews the continuation of the series from the Oxford clay and Coral rag, given in fig. 118, through the upper part of the Oolites into the Wealden beds, which are the lower part of the Cretaceous series above.

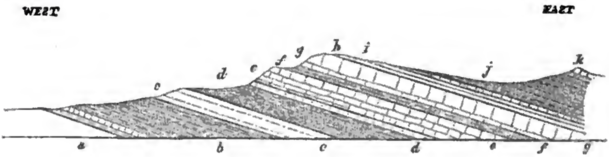


Fig. 118.

Diagrammatic Section of the Gloucestershire Oolites.

	Feet.		Feet.
k. Coral rag - - - - -	50	*e.* Inferior Oolite - - - -	236
j. Oxford clay - - - - -	500	*d.* Upper Lias sand and shale -	300
i. Cornbrash - - - - -	50	*c.* Marlstone - - - - -	200
h. Forest Marble - - -	40	*b.* Lower Lias shale - - - -	600
g. Great Oolite - - - -	200	*a.* Red marls (Top of New Red).	
f. Fuller's Earth - - -	50		

By the examination of these, and many other similar sections in the above-named counties and their neighbourhood, we are enabled to construct the following table of the succession of rock groups in this district. By studying the relations of these rock groups to each other, and a

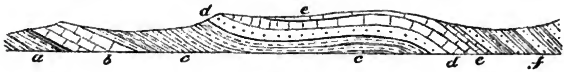


Fig. 119.

Diagrammatic Section of the Dorsetshire Oolites.

	Feet.		Feet.
f. Wealden sands and clays	1400	*c.* Kimmeridge clay . . .	550
e. Purbeck beds	196	*b.* Coral rag	300
d. Portland stone and sands	250	*a.* Oxford clay	600

comparison of the organic remains contained in them, we are also enabled to throw some of them together into larger groups which have a wider range, while, on the other hand, by examination of each group in any particular locality, we may subdivide it into smaller sets of beds that are only to be recognised in that particular locality. The

thicknesses assigned may be taken as the means of the maxima in different places :—

	Feet.		Feet.
12. Purbeck beds .	150	*D.* Portland or Upper Oolites .	900
11. Portland beds .	170		
10. Kimmeridge clay	600		
9. Coral rag . .	180	*C.* Oxford or Middle Ooolites .	800
8. Oxford clay . .	600		
7. Cornbrash . .	80	*B.* Bath or Lower Oolites . .	600
6. Great Oolite .	130		
5. Fuller's earth .	130		
4. Inferior Oolite .	230		
3. Upper Lias . .	300	*A.* The Lias	900
2. Marlstone . .	200		
1. Lower Lias . .	600		
		Total . .	3200

It would not be an unnatural classification of the rock groups if we were to take the *Lias*, the *Oxford Clay*, and the *Kimmeridge Clay*, as the three great clay deposits of the series, each capped by a variable and minor group of sands and limestones, the Lias forming the base of the Bath Oolites, the Oxford clay the base of the Coral rag, and the Kimmeridge clay the base of the Portland Oolites.

The Purbeck beds were at one time grouped with the Wealden beds above them, an arrangement that is not without good arguments in its favour.

A. The Lias.—Essentially a great clay deposit, with occasional bands of a peculiar compact argillaceous limestone near the bottom, and a calcareo-argillaceous sandstone near the middle, with a loose sandy deposit at top connecting it with the group above.

A 1. Lower Lias. At the top of the red marls of the Triassic group is a little layer of hard sandstone full of fragments of bones and teeth of reptiles and fish. In some places bones of Keuper reptiles have been seen in it, and the layer therefore referred to the Trias ; in other places it is full of undoubted Lias fossils. It is probable that there is in reality more than one bone bed, the diminutive representative of those great passage beds between the Trias and the Lias, which are found at Dachstein and Kœssen to have a thickness of upwards of 2000 feet.

In some places the black shales of the Lower Lias rest on the red marls without any bone bed and without any limestone, while in others a group of limestones interstratified with clays, having a thickness of 20 to 50 feet, is seen. Over these limestones occur the ordinary blue clays of which the Lower Lias is generally composed.

A 2. The Marlstone is a well-marked division of the Lias, being more arenaceous than the rest of the formation, and often bound by calcareous or ferruginous cement into a hard stone. In Gloucestershire it is divisible into the hard "rock bed" above, and the sands, often rather argillaceous, below.

It frequently contains bands of ironstone, which have of late years been largely quarried both in the north and south of England.

A 3. Upper Lias. This consists of a great thickness of blue clay, over which are some brown and yellow sands, hitherto classed with the Inferior Oolite, but separated from it on good Palæontological evidence by Dr. Wright of Cheltenham,* and called by him Upper Lias sands, capped by a particular band called the "Cephalopoda bed," from the abundance of those fossils which it contained.

The Upper Lias clay, which is in some places 300 feet thick, thins out towards the south, so that at Uleybury it is only 70 feet thick, and at Lansdown, near Bath, it disappears altogether (*Sheet* 14, *Horizontal Section of the Geological Survey, Messrs. Ramsay and Bristow*).

Characteristic Fossils of the Lias.—Each of the subdivisions of the Lias just described has a peculiar assemblage of fossils characteristic of it in the district where its separation from the rest is obvious. Even the Upper Lias sand may be distinguished palæontologically from the Upper Lias clay in the Gloucestershire district, and has been so separated by Dr. Wright and Mr. Lycett. These subdivisions have more than a local interest, inasmuch as they point distinctly to changes in the forms of life, and therefore to vast lapse of time during the deposition of the beds. The limits of this work, however, do not admit of the details necessary to give a complete account of these subdivisions, for which I must refer the student to Dr. Wright's papers in the *Quarterly Journal of the Geological Society.*

This great abundance of fossils in the Lias, however, makes it difficult to select any short list of species that may be considered more characteristic of the formation than many others that might be mentioned. The following, however, would probably be included in any list :—

Plants.

Equisetites Brodiei	Q. J. G. S. vi., p. 414.
Otopteris obtusa	Foss. gr. 24, *a.*
Palæozamia Bechei and Bucklandi	Geol. Tr. i., t. 7.

Foraminifera.

Polymorphina liassica . . .	Q. J. G. S. ii., p. 30.
Spirilina infima	*Ibid.*

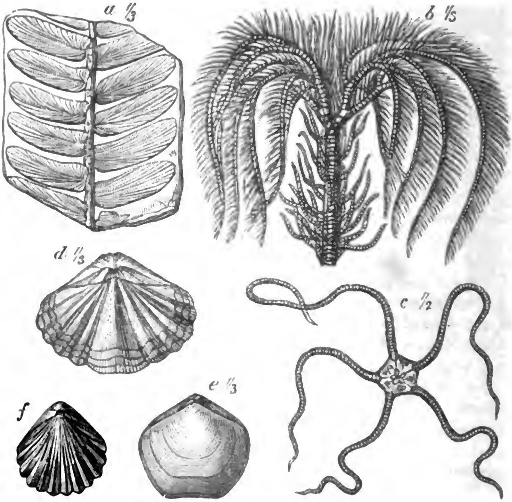
* Wright on "Upper Lias Sands."—*Journal of Geological Society*, vol. xii.

Actinozoa.

Trochocyathus Moorei . .	Pal. Soc. Foss. Cor.*

Brachiopoda.

Leptæna Moorei . . .	Lyell's Man., fig. 404.
Rhynchonella rimosa . .	Foss. gr. 24, *f*.
—— tetrahedra . . .	Tab. View.
Spirifera Walcottii . .	Foss. gr. 24, *d*.
Terebratula numismalis .	Foss. gr. 24, *e*.



Fossil Group No. 24.
Lias Fossils.

a. Otopteris obtusa.
b. Extracrinus Briareus.
c. Ophioderma Egertoni.
d. Spirifera Walcottii.
e. Terebratula numismalis.
f. Rhynchonella rimosa.

Conchifera.

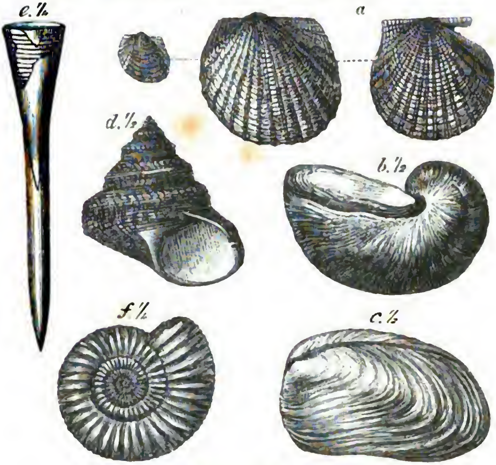
Avicula cygnipes . . .	Tab. View.
—— decussata . . .	Foss. gr. 25, *a*.
Cardinia Listeri . . .	Tab. View.
Gryphæa incurva . . .	Foss. gr. 25, *b*.

* Palæontographical Society, Fossil Corals.

Hippopodium ponderosum	Foss. gr. 25, *c*.
Lima (Plagiostoma) gigantea	Tab. V. and Lyell's Man., fig. 400.
Modiola scalprum . .	Phillips's Man., fig. 205.

Gasteropoda.

Pholadomya ambigua .	Sow. M. C., t. 227.
Pleurotomaria Anglica .	Foss. gr. 25, *d*.



Fossil Group, No. 25.
Lias Fossils.

a. **Avicula decussata.**
b. **Gryphæa incurva**
c. **Hippopodium ponderosum.**
d. **Pleurotomaria Anglica.**
e. **Belemnites elongatus.**
f. **Ammonites communis.**

Cephalopoda.

Ammonites bifrons . . .	Tab. View.
—— communis	Foss. gr. 25, *f*.
—— heterophyllus . . .	Tab. View.
—— obtusus	Tab. View.
—— planicostatus . . .	Tab. View.
—— serpentinus	Tab. View.
Belemnites elongatus . . .	Foss. gr. 25, *e*.
—— tubularis	Tab. View.
Nautilus truncatus . . .	Tab. View.

Echinodermata.

Diadema serialis . .	Phillips's Man., fig. 194.
Extracrinus Briareus .	Foss. gr. 24, *b*.
Ophioderma Egertoni .	Foss. gr. 24, *c*.
Uraster Gaveyi . .	M. G. S., Dec. 3.

Fish.

Acrodus nobilis . .	Lyell's Man., fig. 412.
Æchmodus Leachii . .	Lyell's Man., fig. 411.
Dapedius politus . .	Tab. View.
Hybodus reticulatus .	Lyell's Man., fig. 413.

Reptiles.

Ichthyosaurus communis .	Tab. V. and Lyell's Man., etc.
Plesiosaurus dolichodeirus	*Ib.* *Ib.*
Pterodactylus* macronyx .	Geol. Trans., vol. iii.
Teleosaurus Chapmanni.	

B. The Bath or Lower Oolites.

4. *The Inferior Oolite* comprises those beds which come next above the Cephalopoda bed of the Upper Lias sands, and thus form the lowest group of the Lower Oolites. According to the data given in sheet 59 of the Horizontal Sections of the Geological Survey, it is in the hills to the north-east of Cheltenham, to be subdivided into—

		Feet.
e.	The Ragstone .	40
d.	Upper Freestone .	34
c.	Oolite Marl .	7
b.	Lower Freestone .	147
a.	The Pea Grit .	38

The *Pea Grit* is a pisolitic limestone, consisting of a number of flat concretions like large flattened peas.

The *Freestones* are fine-grained, pale, oolitic, or shelly limestones, containing near the top a seven foot bed of brown marl, *c*, with an imperfect oolitic structure.

The *Ragstone* is a brown sandy limestone, sometimes hard and firm, at others incoherent.

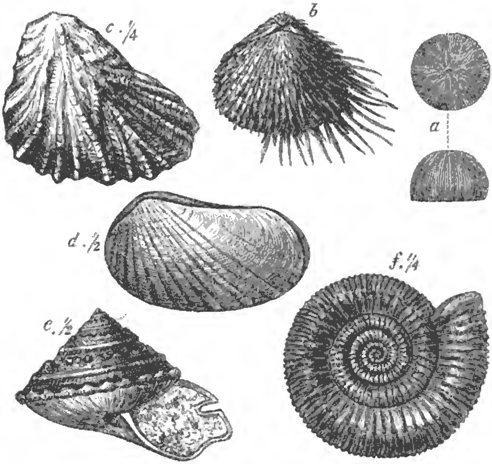
In this neighbourhood even these subdivisions have their characteristic fossils.

As we recede from this neighbourhood, however, these subdivisions

* Most manuals give figures of Ichthyosauri, Plesiosauri, Pterodactyli, etc.; see especially Buckland's "Bridgewater Treatise," etc., and Mr. Waterhouse Hawkins's Diagrams.

naturally die out and disappear ; other beds of coarse limestone, sometimes oolitic, and sometimes sandy, taking their place.

In Oxfordshire, indeed, according to Professor Phillips, the whole group of the Inferior Oolite disappears, neither the beds nor the peculiar fossils being discoverable.—*(Statement at British Association, Oxford,* 1860.)



Fossil Group No. 26.
Inferior Oolite Fossils.

a. Anabacia hemispherica.
b. Rhynchonella spinosa.
c. Ostrea Marshii.
d. Pholadomya fidicula.
e. Pleurotomaria ornata.
f. Ammonites Humphresianus.

Characteristic Fossils of the Inferior Oolite.

Actinozoa.	
Anabacia hemispherica	Foss. gr. 26, *a.*
Montlivaltia trochoides	Pal. Soc. Foss. Cor.
Brachiopoda.	
Rhynchonella spinosa	Foss. gr. 26, *b.*
Terebratula carinata	Pal. Soc. Dav. Brach.*
——— fimbria	Tab. View.
——— perovalis	Tab. View.

* Palæontographical Society, Davidson's Brachiopoda.

Conchifera.

Astarte elegans	Tab. View.
Gresslya abducta	Phill. G. Y. i., t. 11.
Lima pectiniformis (proboscidea) .	Tab. View.
Ostræa Marshii	Foss. gr. 26, *c*.
Pecten dentatus	Sow. M. C. 574.
Pholadomya fidicula	Foss. gr. 26, *d*.

Gasteropoda.

Chemnitzia lineata	Sow. M. C. 218.
Pleurotomaria elongata	*Ibid.*, 193.
——— ornata	Foss. gr. 26, *e*.
——— pallium	Sow. M. C. 221.

Cephalopoda.

Ammonites Brocchii	Sow. M. C. 202.
——— Brodiæi	*Ibid.*, 351.
——— Brongniartii . . .	Phillips's Man., fig. 238.
——— Humphresianus . . .	Foss. gr. 26, *f*.
——— Murchisonæ . . .	Sow. M. C. 550.
——— Parkinsoni	Tab. View.
&c. &c.	
Belemnites ellipticus	Geol. Trans. ii., t. 8.
Nautilus sinuatus	Sow. M. C. 194.

Echinodermata.

Dysaster ringens	Tab. View.
Echinus perlatus	Tab. View.
Nucleolites Agassizii	Ann. Nat. Hist. 1852.

Fish.

Pholidophorus Flesheri . . .	Agassiz.
Strophodus subreticulatus . . .	Agassiz.

5. *The Fuller's Earth.*—Above the Inferior Oolite comes, in the Gloucestershire district, a series of blue and yellow shales, clays, and marls, some of which are of the peculiar kind of clay called Fuller's earth, the name assigned to the group. Interstratified with these are occasional bands of limestone.

The maximum thickness is about 150 feet, rather rapidly diminishing in all directions.

Characteristic Fossils.—None, unless the little oyster called Ostræa acuminata (*Tabular View* and *Lyell's Manual*, fig. 386); the other fossils contained in it are a mixture of Inferior Oolite and Great Oolite species.

6. *Great Oolite.*—This, like the other oolitic groups, except the clays, has a very variable lithological character. Mr. Lycett says that near Minchinhampton it is made up of Weatherstones, Sandstones, and Limestones; the Weatherstones (shelly calcareous sandstones) being always at the base of the group, but passing laterally into Sandstones, which are commonly covered by Limestones, while the Weatherstones have never any of the Limestones above them.—(*Journal Geological Society*, vol. iv.; and *Palæontological Society*, 1850).

Mr. Hull divides the Great Oolite near Cheltenham into two zones. *a.* The Under zone, a variable series of sandy flags, "slates," and blue limestones, with white oolitic free-stones, showing much oblique lamination. The flaggy limestones, and sometimes the thick bedded ones, split in some places into very thin slabs, which are called, though erroneously, "slates." The Stonesfield slate, so celebrated for its terrestrial reptiles and mammalian remains, belongs to these beds, and might therefore give its name to the zone. The Collyweston slate of Northampton, also belongs to this zone. Its average thickness is 50 feet. *b.* The upper zone is well marked in Gloucestershire, by the occurrence of a bed of marl at its base, and a band of hard white limestone at its summit, the intermediate beds being oolitic limestones, sandstone or sandy limestone, greatly marked by oblique lamination. Its thickness is 150 feet.—(*Memoirs of the Geological Survey*, 1857).

Characteristic Fossils of the Great Oolite.

Plants.

Equisetum columnare . .	Phillips's Man., fig. 218, and Mantell's Meds. fig. 13.
Pterophyllum comptum . .	Foss. gr. 27, *a*.
Tæniopteris latifolia . . .	Mantell's Meds., fig. 26.
—— vittata	Phillips's Man., fig. 217.
Thuytes expansus . . .	Phill. G. Y. i., t. 10.

Actinozoa.

Isastræa Conybeari . . .	Pal. Soc. Foss. Cor.

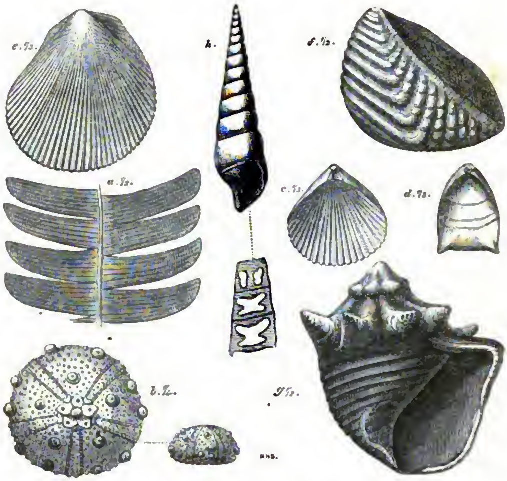
*Brachiopoda.**

Rhynchonella concinna . .	Foss. gr. 27, *c*.
Terebratula coarctata . .	Tab. View.
—— digona	Foss. gr. 27, *d*.
—— maxillata . . .	Tab. View.

* Messrs. Lycett and Morris have published the Mollusca of the Great Oolite in the volumes of the Palæontographical Society, referred to in the succeeding pages.

Conchifera.

Arca Hirsonensis	Phill. G. Y., t. 11, fig. 43.
Gervillia lanceolata	Tab. View.
Lima cardiiformis	Foss. gr. 27, *e*.
Pachyrisma grande	Pal. Soc. Ool. Biv.
Pholadomya acuticosta	Tab. View.
Pteroperna costatula	Pal. Soc. Ool. Biv.
Trigonia Goldfussii	Foss. gr. 27, *f*.
—— impressa	Tab. View.



Fossil Group No. 27.
Great Oolite Fossils.

a. Pterophyllum comptum.
b. Hemicidaris minor.
c. Rhynchonella concinna.
d. Terebratula digona.
e. Lima cardiiformis.
f. Trigonia Goldfussii.
g. Purpuroidea Morrissii.
h. Nerinæa Voltzii.

Gasteropoda.

Alaria atractoides	Pal. Soc. Ool. Foss.
Cylindrites acutus	Lyell's Man., fig. 369.
Nerinæa Voltzii	Foss. gr. 27, *h*.

Patella rugosa	Lyell's Man., fig. 370.
Purpuroidea Morrissii . . .	Foss. gr. 27, *g*.
Trochotoma annuloides . . .	Pal. Soc. Ool. Foss.

Cephalopoda.

Ammonites gracilis	Pal. Soc. Ool. Mol.
Belemnites fusiformis . . .	Tab. View.
—— Waterhousei.	
Nautilus Baberi	Pal. Soc. Ool. Mol.

Echinodermata.

Hemicidaris minor	Foss. gr. 27, *b*.
Pseudodiadema pentagonum . .	Pal. Soc. Brit. Ech.*

Fish.

Asteracanthus semisulcatus . .	Agassiz's Fossil Fish.
Pholidophorus minor . . .	
Strophodus magnus	

Reptiles.

Megalosaurus Bucklandi . . .	Mantell's Meds., ch. xvii

Mammalia.

Amphitherium Prevostii . . .	Lyell's Man., fig. 375.
Phascolotherium Bucklandi . .	*Ibid.*, fig. 382.
Stereognathus Ooliticus . . .	Q. J. G. S., vol. xiii.

7. *The Cornbrash and Forest Marble Group.*—This is a very variously composed set of clays, sands, and limestones, containing local subdivisions such as the Bradford Clay, the Forest Marble, and the Cornbrash itself.

The Bradford Clay is a blue unctuous clay occurring at Bradford, and extending for a few miles around it; it is never more than forty or fifty feet in thickness; locally full of Apiocrinites Parkinsoni (rotundus). Foss. gr. 28, *b*.

The Forest Marble (so named from Wychwood Forest) is composed of coarse fissile oolite, with much oblique lamination, hard shelly limestones, blue marls and shales, yellow siliceous sand, with large spheroidal blocks of limestone, and fine oolitic freestone. It is rarely more than forty, never more than eighty feet thick.

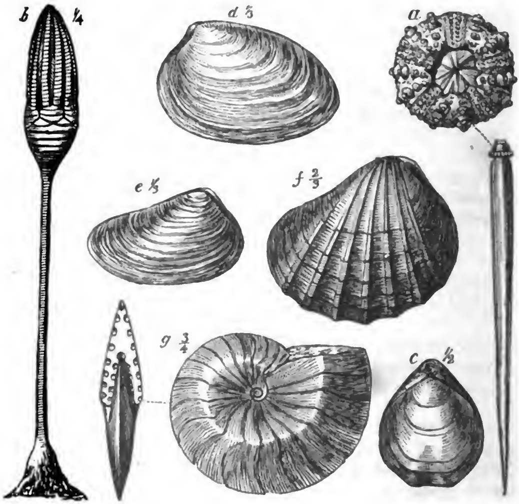
The Cornbrash is generally a rubbly cream-coloured limestone in thin beds, always nodular and concretionary, each fragment having a deep red coating. Not more than fifteen feet thick.

* British Fossil Echinodermata by Dr. T. Wright.

Characteristic Fossils of the Cornbrash and Forest Marble Group.

Brachiopoda.

Terebratula intermedia	. . .	Foss. gr. 28, *c.*
———— obovata	. . . . .	Tab. View.



Fossil Group No. 28.
Cornbrash and Forest Marble Fossils.

a. Acrosalenia hemicidaroides.
b. Apiocrinus Parkinsoni.
c. Terebratula intermedia.
d. Gresslya peregrina.
e. Myacites decurtata.
f. Pholadomya lyrata.
g. Ammonites discus.

Conchifera.

Avicula echinata	. . . .	Tab. View.
Ceromya concentrica	. . . .	Sow. M. C. 491.
Gresslya peregrina	. . . .	Foss. gr. 28, *d.*
Isocardia minima	. . . . .	Tab. View.
Lima rigidula	. . . . .	Phill. G. Y., t. 7.

Modiola bipartita	Phill. G. Y., t. 4.
Myacites decurtata . . .	Foss. gr. 28, *e*.
——— securiformis . . .	Phill. G. Y., t. 7.
Pecten fibrosus	*Ibid.*, t. 6.
—— vagans	Pal. Soc. Ool. Mol.
Pholadomya deltoidea . . .	Sow. M. C. 197.
—— lyrata	Foss. gr. 28, *f*.

Gasteropoda.

Chemnitzia vittata	Phill. G. Y., t. 7, fig. 15.

Cephalopoda.

Ammonites discus	Foss. gr. 28, *g*.

Echinodermata.

Acrosalenia hemicidaroides . .	Foss. gr. 28, *a*.
Apiocrinus Parkinsoni . . .	Foss. gr. 28, *b*.
Nucleolites clunicularis . . .	Tab. View.

Annelida.

Serpula tetragona	Sow. M. C. 599.

Fish.

Asteracanthus acutus . . .	Ag. foss. fish.
Cardiodon rugulosus.	

The Bath or Lower Oolites of Yorkshire.—The beds which lie between the Lias and the Oxford Clay preserve the structure above given, with more or less constancy, from Somersetshire into Lincolnshire, forming a continuous ridge, with an unbroken escarpment, till we reach the estuary of the Humber. A little north of that river the whole Oolitic series, with the exception of the Lias, is overlapped and concealed by the beds of the Cretaceous series, from underneath which, however, they gradually reappear again farther north, and the Lower Oolites rise from beneath the Oxford Clay into some wild hills called the Yorkshire Moorlands, which end in precipitous cliffs along the coast about Whitby and Scarborough.

In this district the changes, often apparent as we trace the Lower Oolites from Somerset into Lincolnshire, are found to have been still further carried out, so that, instead of the groups just described, we get the following section, which is condensed from Professor Phillips's descriptions (*Q. J. Geol. Soc.*, vol. xi. p. 84) :—

	Feet.
5. Shelly Cornbrash, limestone of Gristhorp and Scarborough	10
4. Sandstones, shales, ironstones, and coals of Gristhorp, Scarborough, and Scalby, enclosing some calcareous shelly bands	200
3. Shelly oolite, and clays of Cloughton and West Nab	60
2. Sandstones, shales, ironstones, and workable coal of the Peak, Stainton Dale, and Haiburn Wyke	500
1. Irony sandstone and subcalcareous beds, with bands of shells and plants	60

It is singular that the little insignificant-looking band called Cornbrash continues lithologically and palæontologically the same as in the south of England, while so great a change takes place in the more important beds below.

The Characteristic Fossils of the Lower Oolites of Yorkshire are principally plants, many of which are ferns. The following genera may be mentioned, some of which have different species in these beds and in the Carboniferous formation, while those marked with one asterisk are only Mesozoic, and those with two exclusively Oolitic genera.

Cyclopteris, Equisetites, ** Otopteris, ** Pachypteris, ** Palæozamia, Pecopteris, ** Phlebopteris, * Pterophyllum, ** Sagenopteris (Glossopteris), Sphenopteris, ** Tæniopteris, * Thuytes, ** Zamites. — (*See Mantell's Meds.*, chap. vi., for figures of some of these.)

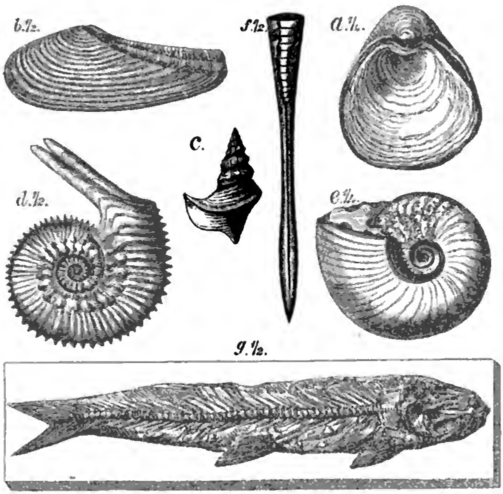
Some of the Equisetites are found erect ; and we have here an imperfect coal formation of the Oolitic period, the coals of which only differ from those of the Carboniferous formation in quantity and economic value.

C. The Oxford or Middle Oolites.

This division comprises the Oxford Clay and the Coral Rag groups—

8. *The Oxford Clay* is so called as lying beneath the plain on which Oxford stands, but it extends across England from Weymouth in Dorset to Filey Bay in Yorkshire. It is generally a dark blue clay, sometimes dark gray, approaching to black. In its lower portion it has occasionally some beds of tough calcareous sandstone, with brown sands, called Kelloway rock, from a place in Wiltshire. This Kelloway rock appears to be wanting in the Midland counties as a distinct rock, though its peculiar fossils occur in the lower part of the Oxford clay. It reappears in Yorkshire with the same characters and fossils as in the south. The maximum thickness of the Kelloway rock is 80 feet. That of the whole Oxford clay, including it, cannot be less in some places than 600 feet.

Characteristic Fossils of the Oxford Clay.—The fossils of the Oxford clay are numerous, and often very beautiful, the shells frequently retaining their iridescence from having been packed in close clay, or being converted, like those in the Lias, into brilliant iron pyrites. The following list includes a few of the most common species :—



Fossil group No. 29.
Characteristic Fossils of the Oxford Clay.

a. Gryphæa dilatata.
b. Anatina undulata.
c. Alaria composita.
d. Ammonites Jason.
e. Ammonites excavatus.
f. Belemnites hastatus.
g. Leptolepis macrophthalmus.

Conchifera.

Anatina undulata	Foss. gr. 29, *b.*
Astarte lurida	Phill. G. Y., t. 5, fig. 2.
Gryphæa dilatata	Foss. gr. 29, *a.*
Myacites recurva	Phill. G. Y., t. 5, fig. 25.
Ostræa undosa	*Ibid.*, t. 6, fig. 4.

Gasteropoda.

Alaria composita	Foss. gr. 29, *c.*

Cephalopoda.

Ammonites calloviensis . . .	Tab. View.
——— cordatus	Tab. View.
——— excavatus	Foss. gr. 29, *e*.
——— Jason	Foss. gr. 29, *f*.
——— Lamberti	Sow. M. C., 242.
——— modiolaris (sublævis) . .	Tab. View.
Belemnites hastatus	Foss. gr. 29, *f*.
——— Puzosianus* . . .	Tab. V. and Ly. Man.
Nautilus hexagonus	Tab. View.

Annelida.

Serpula vertebralis	Sow. M. C., 599.

Cirripedia.

Pollicipes concinnus	Sow. M. C., 647.

Crustacea.

Mechocheirus Pearcei	Ann. Nat. H., 1849.

Fish.

Aspidorhynchus euodus . . .	Q.J.G.S., vol. i., p. 231.
Lepidotus macrocheirus . . .	*Ibid.*
Leptolepis macrophthalmus . .	Foss. gr. 29, *g*.

9. *The Coral Rag or Corraline Oolite* was so called from the abundance of corals contained in its lower beds in some parts of Oxfordshire and Wiltshire. Like all the other calcareous or arenaceous groups of the Oolite, this is very irregular, and subject to great variations in character and thickness. There is a pretty close general resemblance in the Yorkshire and Wiltshire types, while in the intermediate district the whole group seems to disappear. It may be divided into three sub-groups—

				Feet.
c. Upper calcareous grit, maximum thickness			.	60
b. Coralline Oolite,	"	"	.	50
a. Lower calcareous grit,	"	"	.	80

a. The lower beds in Yorkshire are a series of gray marly sandstones seventy feet thick, passing up into cherty limestone, covered by sands full of great calcareous concretions capped by strong calcareous sandstones.

b. A variable group of irregular masses of nodules made of corals compacted together, often earthy, and connected by blue clay, passing

* See also Mantell's Medals, figs. 143 and 144, and description.

into blue crystalline limestone, alternations of hard shelly Oolite, and soft perishable limestone, and in Wiltshire a rubbly nodular Oolite, sometimes pisolitic.

c. The Upper group, obscurely indicated in the south, is in the north like group *a*, but more ferruginous and less cherty, passing up by intercallation into the Kimmeridge clay above.—(*Phillips.*)

The Coral rag may be examined either in Dorsetshire and Wiltshire, in Shotover Hill in Oxfordshire, or on the coast of Yorkshire, about Scarborough and Filey.

At Shotover Hill, however, considerable erosion of its upper part took place before the deposition of the Kimmeridge clay, all the upper calcareous grit having been removed.—(*Phillips.*)

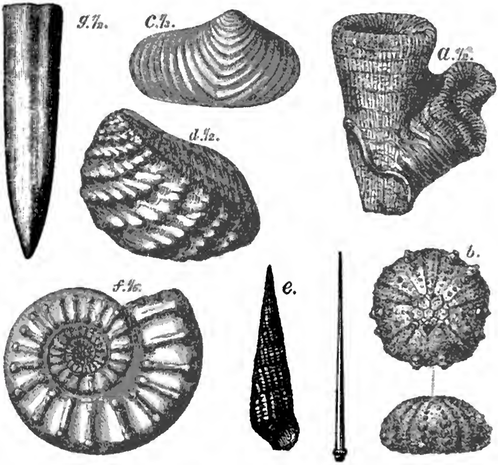
Characteristic Fossils of the Coral Rag.

Plants.	
Carpolithes Bucklandi . . .	Lind. F. F.,* 189.
—— conicus	*Ibid.*
Actinozoa.	
Calamophyllia Stokesii . .	Tab. View.
Isastræa explanata . . .	Tab. View.
Stylina tubulifera . . .	Tab. View.
Thamnastræa arachnoides . .	Tab. View.
Thecosmilia (Caryophyllia) annularis	Foss. gr. 30, *a.*
Conchifera.	
Goniomya literata . . .	Foss. gr. 30, *c.*
Lima (Plagiostoma) rigida . .	Tab. View.
Ostræa gregaria	Ly. Man. 356, and Tab. V.
Pecten vimineus	Sow. M. C., 543.
Pholadomya æqualis . . .	*Ibid.*
Trigonia costata	Tab. View.
Gasteropoda.	
Cerithium muricatum . . .	Foss. gr., 30. *e.*
Chemnitzia Heddingtonensis .	Tab. View.
Nerinæa Goodhallii . . .	Ly. Man. 358, and Tab. V.
—— hieroglyphica . . .	Ly. Man. 357.
Phasianella (chemnitzia) striata .	Tab. View.
Cephalopoda.	
Ammonites perarmatus . .	Foss. gr. 30, *f.*
—— vertebralis . . .	Tab. View.
Belemnites abbreviatus . .	Foss. gr. 30, *g.*

* Lindley and Hutton's Fossil Flora.

Echinodermata.

Acrosalenia decorata . . .	Foss. gr. 30, *b.*
Cidaris coronata . . .	Ly. Man. 360.
—— florigemma . . .	Phil. Man. 242.
Hemicidaris intermedia . .	Tab. V., and Mantell's Meds., fig. 101.
Nucleolites scutatus (dimidiatus) .	Phil. Man. 244.



Fossil Group No. 30.
Coral Rag Fossils.

a. Thecosmilia annularis.
b. Acrosalenia decorata.
c. Goniomya literata.
d. Trigonia clavellata.*
e. Cerithium muricatum.
f. Ammonites perarmatus.
g. Belemnites abbreviatus.

Crustacea.

Glyphæa scabrosa	Phill. G. Y. vol. i. p. 170.

Fish.

Gyrodus Cuvieri	Ag. Poiss. foss.
Hybodus obtusus	*Ibid.*

* This is a Kimmeridge clay and Portland stone fossil according to Morris's Catalogue.

D. THE UPPER OR PORTLAND OOLITES consist of three groups, namely ;—10. The Kimmeridge Clay ; 11. The Portland beds ; and, 12. The Purbeck beds—the two latter groups being only known in the southern part of England.

10. *The Kimmeridge Clay* is so called from the village of Kimmeridge on the coast of Dorsetshire, a little west of St. Alban's Head. It is traceable through Wiltshire and Buckinghamshire, gradually thinning out from a thickness of 500 or 600 feet, till it seems to disappear in Huntingdon and Cambridgeshire. It is again visible in Lincolnshire, and largely in the vale of Pickering in Yorkshire. It is in some places a dark gray shaly clay, in others brownish or yellowish, containing bands of sand or of calcareous grit, or ferruginous Oolite, and layers of nodules of septaria. In some places, especially in the district about the Isle of Purbeck, it becomes very carbonaceous, and the "bituminous shale" sometimes passes into layers of "brown shaly coal." Layers of a particular kind of oyster, called the *Ostræa deltoidea*, occur abundantly in many places, always appearing "in broad continuous floors parallel to the planes of stratification, the valves usually together, with young ones occasionally adherent to them, and entirely embedded in clay, without nodules or stones of any kind, and without any organic remains in the layers."—(*Phillips's Man.* p. 311.)

Characteristic Fossils of the Kimmeridge Clay.

Brachiopoda.

Rhynchonella inconstans .	Foss. gr. 31, *a*.

Conchifera.

Astarte Hartwelliensis .	Foss. gr. 31, *c*.
Cardium striatulum . .	Ly. Man. 349.
Exogyra (Gryphæa) virgula .	Foss. gr. 31, *b*.
Ostræa deltoidea . . .	Ly. Man., 350 ; Phil. Man. 258, and Tab. View.
Pinna granulata . . .	Sow. M. C., 347.
Thracia depressa . .	Foss. gr. 31, *d*.
Trigonia clavellata . .	Foss. gr. 30, *d*.

Gasteropoda.

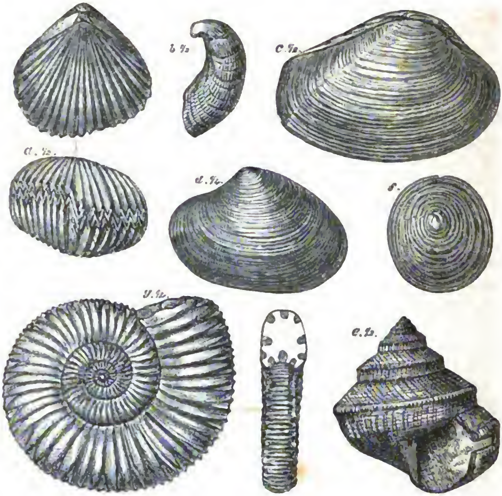
Chemnitzia gigantea.	
Patella latissima . . .	Foss. gr. 31, *f*.
Pleurotomaria reticulata .	Foss. gr. 31, *e*.

Cephalopoda.

Ammonites biplex . .	Foss. gr. 31, *g*.
—— rotundus . . .	Sow. M. C., 293.
—— triplicatus . . .	*Ibid.* 92.

Fish.

Asteracanthus ornatissimus . .	Ag. Poiss. foss.
Hybodus acutus	*Ibid.*
Sphærodus gigas	*Ibid.*



Fossil Group No. 31.
Kimmeridge Clay Fossils.

a. Rhynchonella inconstans.
b. Exogyra virgula.
c. Astarte Hartwelliensis.
d. Thracia depressa.
e. Pleurotomaria reticulata.
f. Patella latissima.
g. Ammonites biplex.

Reptiles.

Ichthyosaurus trigonus . . .	Ow. Brit. Ass. Rep.
Plesiosaurus affinis	*Ibid.*
Pliosaurus (the genus) . . .	*Ibid.*
Steneosaurus rostro-minor . .	*Ibid.*
Teleosaurus asthenodeirus . .	*Ibid.*

11. *The Portland Beds*, so called from the promontory known as the Isle of Portland, on the coast of Dorset, have, like most of the other stony groups of the Oolitic series, a variable composition. They consist of sands and sandstones below, becoming calcareous and passing into Oolitic limestone above. They are therefore divisible into—

b. Portland stone, consisting of white Oolite and beds locally termed "stonebrash" and "roche," etc., interstratified with clays, and containing layers of flint; about 90 to 100 feet.

a. Portland sands, consisting of brown or yellow sands and sandstones, full of green grains, like those afterwards to be described in the Greensands; about 80 feet.

The beds, especially the lower sands, are to be seen at intervals capping the Oolitic hills as far north as Oxfordshire, where they occur about the summit of Shotover Hill. They consist there of sands with marine fossils, over which are "iron sands" with fresh-water forms.—(Phillips's *Brit. Assoc.* Oxford 1860.) Farther north they entirely disappear, for at Ely the Lower Greensand of the Cretaceous series rests directly on the Kimmeridge clay.

Characteristic Fossils of the Portland Beds.

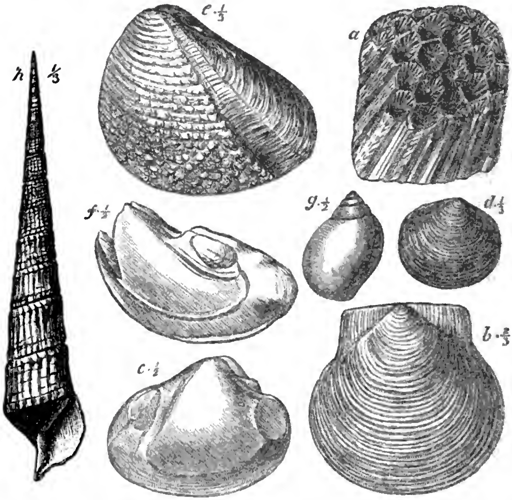
Actinozoa.	
Isastræa oblonga	Foss. gr. 32, *a.*
Conchifera.	
Astarte cuneata	Sow. M. C., 137.
Cardium dissimile	Foss. gr. 32, *c.*
Lima obliquata	G. Tr. 2, vol. ii. p. 319.
Lucina Portlandica	Foss. gr. 32, *d.*
Modiola pallida.	Sow. M. C., 8.
Ostræa expansa	*Ibid.* 238.
Pecten lamellosus	Foss. gr. 32, *b.*
Trigonia gibbosa	Foss. gr. 32, *e.*
—— incurva	Foss. gr. 32, *f.*
Gasteropoda.	
Cerithium Portlandicum . . .	Foss. gr. 32, *h.*
Natica elegans	Foss. gr. 32, *g.*
Neritoma sinuosa	Tab. View.
Pleurotomaria rugata.	
Turritella concava	Sow. M. C., 565.
Cephalopoda.	
Ammonites giganteus . . .	Tab. View.

Echinodermata.

Hemicidaris Davidsoni . .	Wright, Foss. E. Pal. Soc.

Fish.

Caturus argustus . . .	Ag. Poiss. foss.
Hybodus strictus . . .	*Ibid.*
Ischyodus Townshendi . .	*Ibid.*



Fossil Group No. 32.
Portland Fossils.

a. Isastræa oblonga.
b. Pecten lamellosus.
c. Cardium dissimile (internal cast).
d. Lucina Portlandica.
e Trigonia gibbosa.
f Trigonia incurva (internal cast).
g Natica elegans.
h Cerithium Portlandicum.

Reptiles.

Cetiosaurus longus	Ow. Brit. Ass. Rep.

12. *The Purbeck beds* are so named from their being well developed, and clearly exhibited in the district, south of the Poole estuary in Dorsetshire, which is known as the Isle of Purbeck. They differ from

all the Oolitic series below, in being of fresh-water origin. They are from that circumstance more nearly allied to the Wealden beds above than to the Oolites below, but they contain some marine and other species of fossils, which seem to link them to the Oolites.

Not far above the top of the Portland stone, on which the shelly limestones of the Purbeck beds repose, there occur one or two "dirt beds," as they are called by the quarrymen, which are in fact old vegetable soils, including the roots and stems of fossil plants, the remains of an old forest. We have here then actual land surfaces, which having been formed over the marine beds, in consequence, probably, of the gradual elevation of the latter above the sea, were subsequently buried beneath fresh-water deposits which were formed either in a lake or in the bed of a large tranquil river, that spread over the land in consequence, probably, of its having suffered from depression.

The Purbeck beds, although they have not a greater thickness than 150 or 200 feet, were examined and described in great detail by Professor Edward Forbes, and subsequently by Mr. Bristow, whose observations will be found in sheet 56 of the Horizontal Sections and sheet 22 of the Vertical Sections of the Geological Survey of Great Britain, in the latter of which every bed is drawn on a scale of 1 inch to 10 feet, with full lithological and palæontological descriptions.

Edward Forbes divided the Purbeck beds into three groups, Lower, Middle, and Upper, which, without any marked lithological distinctions, nevertheless contain each a peculiar assemblage of fossils.

Mr. Bristow's section of Durlstone hill contains the following groups :—

			Feet.	
Upper.		20. Upper Cypris clays and shales .	45	60
		19. Unio beds with the Crocodile bed .	5	
		18. Upper broken shell limestone —— (soft burr) .	19	
Middle.		17. Chief "beef"* beds . . .	28	130
	Marine Beds.	16. Corbula beds	33	
		15. Scallop beds (white roach) . .	4	
		14. Leaning vein	6	
		13. Royal (limestone). . . .	5	
		12. Freestone vein	21	
		11. Downs vein	12	
		10. Cinder bed (mass of small Ostræa distorta)	8	
		9. Cherty fresh-water beds . .	8	
		8. Marly fresh-water beds . .	5	
		Carry forward .		190

* The quarrymen give the name of "beef" to beds of fibrous carbonate of lime.

			Feet.
	Brought forward		190
Lower.	7. Marly fresh-water beds	7	130
	6. Soft cockle beds	60	
	5. Hard cockle beds	9	
	4. Cypris freestone	34	
	3. Broken bands	14	
	2. Soft Cap	6	
	1. Hard Cap, with dirt parting at bottom	10	
			330

At Worbarrow Bay and Mewps Bay, an irregular dirt bed comes in between the hard and soft Caps, but is not seen at Ridgway Hill according to the Rev. Osmond Fisher. The whole section gradually gets thinner at those places, till it is not more than 190 feet at the latter.

It was in a little band about 20 feet below the cinder bed, that the very remarkable discoveries of several Mammalian remains were made by Mr. Beckles.

The Purbeck marble, formerly so much used in the internal decoration of churches and other buildings, was procured from bands of limestone, consisting almost entirely of compacted fresh-water snailshells (Paludina carinifera), which was interstratified with the Upper Cypris clays and shales No. 20.

Characteristic Fossils of the Purbeck beds.

Plants.

Cycadeoidea microphylla	Foss. gr. 33, *a*.
—— megaphylla	Mantell's Meds. fig. 50.
Dammarites Fittoni	G. Tr. 2 ser., vol. iv.

Conchifera.

Cyrena elongata	Foss. gr. 33, *b*.
Ostræa distorta	Tab. View.

Gasteropoda.

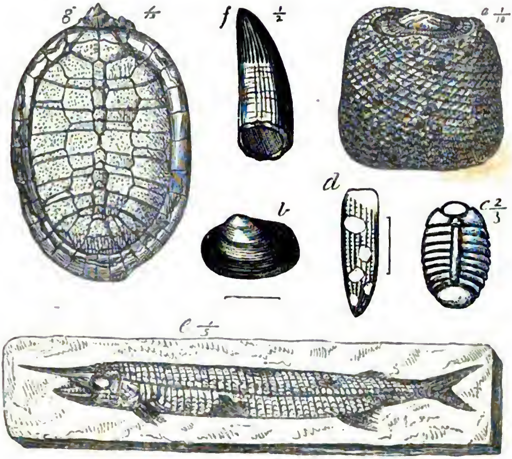
Melanopsis harpæformis	
Physa Bristovii	Tab. V., and Ly. Man. 338.
Paludina carinifera	Sow. M. C., 509.

Echinodermata.

Hemicidaris Purbeckensis	Ly. Man. 336, and Phil. Man. 267.

Crustacea.

Archæoniscus Edwardsii . .	Foss. gr. 33, *c.*
Cypridea tuberculata .	Ly. Man., fig. 334, and Mant. Meds., fig. 174.
—— fasiculata	Ly. Man. 337.
—— Purbeckensis . .	Ly. Man. 339.



Fossil Group No. 33.

Purbeck Fossils.

a. Cycadeoidea microphylla.
b. Cyrena elongata.
c. Archæoniscus Edwardsii.
d. Bupreston stygnus (elytron of).
e. Aspidorhynchus Fisheri.
f. Goniopholis crassidens.
g. Pleurosternon ovatum.

Insects.

Æshna perampla . . .	Brod. Foss. In., pl. v.
Bupreston stygnus . . .	Foss. gr. 33, *d.*
Carabus elongatus . . .	Brod. Foss. In., pl. ii.

Fish.

Aspidorhynchus Fisheri . .	Foss. gr. 33, *e.*
Lepidotus Mantelli . . .	Mantell's Meds., fig. 196.
Microdon radiatus . . .	Ag. Poiss. foss.
Ophiopsis breviceps . . .	M. G. S., Dec. 6.
Pholidophorus ornatus . .	Ag. Poiss. foss.

Reptiles.

Goniopholis crassidens (*Crocodilian*)	Foss. gr. 33, *f*, and Mantell's Meds., fig. 207.
Pleurosternon ovatum . .	Foss. gr. 33, *g*.
Macellodus Brodiei . . .	Q. J. G. S., vol. x.
Nothetes destructor . . .	*Ibid.* *Ibid.*

Mammalia.

Spalacotherium Brodiei . .	*Ibid.* *Ibid.*
Plagiaulax Becklesii . . .	*Ibid.*, vol. xiii.

Fossils Characteristic of more than one Group.—In selecting groups of species that are peculiarly characteristic of certain groups of beds, certain other species are necessarily omitted that are characteristic of larger parts of the series, being found in almost equal abundance in more than one group.

Of these the following deserve mention :—

Species common to A (Lias), and B (Bath Oolites).

Brachiopoda, Thecidium triangulare ranges from Upper Lias to Cornbrash (*Lycett*).

Species common to A and C (Coralline Oolite).

Conchifera, Modiola cuneata.

Species common to B and C.

Actinozoa, Thamnastræa concinna.
Polyzoa, Heteropora ramosa.
Brachiopoda, Rhynchonella varians, Terebratula impressa, ornithocephala.
Conchifera, Anatina undata, Gervillia siliqua, Isodonta triangularis, Lima duplicata, Pecten annulatus, demissus, Pinna lanceolata, mitis, Arca æmula, Cucullæa elongata, oblonga, Goniomya litterata and scripta, Isocardia tenera, Lithodomus inclusus, Lucina crassa, Myacites calceiformis, Quenstedtia lævigata.
Gasteropoda, Alaria trifida, Bulla elongata, Pleurotomaria granulata, Purpurina nodulata.
Cephalopoda, Ammonites macrocephalus.
Echinodermata, Echinus perlatus, Hemicidaris intermedia, Nucleolites orbicularis, scutatus, and sinuatus, Pygaster semisulcatus, Pygurus pentagonalis.
Crustacea, Glyphæa rostrata.

Species common to B, C, and D (Portland Oolites).

Conchifera, Trigonia costata.

Species common to B and D.

Conchifera, Cardium striatulum, Pecten arcuatus, Pholadomya ovalis.

Species common to C and D.

Brachiopoda, Lingula ovalis.
Conchifera, Astarte ovata, Exogyra nana, Gervillia aviculoides, Lima rustica, Ostræa solitaria, Trigonia clavellata.

Scotland.—Patches of Lias and Oxford Clay, some of which are estuary beds, occur here and there on the islands of Mull and Skye, and other parts of the western coast of Scotland. Near Brora, on the east coast of Sutherlandshire, rocks similar to the Lower Oolites of Yorkshire are found, containing similar beds of impure coal (see papers by Sir R. I. Murchison, *Trans. Geol. Soc.,* vol. ii., second series, and by Professor Edward Forbes, *Quart. Jour. Geol. Soc.,* vol. vii., etc.; and *First Sketch of New Geol. Map of Scotland,* by Sir R. I. Murchison and Arch. Geikie.

Ireland.—The only beds belonging to the Oolitic series in Ireland are some black Liassic shales which are visible in some parts of Antrim. These occur just at the top of the red marls of the Trias, and are probably the basal beds of the Lias. They do not anywhere exceed thirty or forty feet in thickness, but contain often an abundance of characteristic Lias fossils (see fig. 122).

The district of the Jura Mountains.—It has already been said that on the Continent the Oolitic series is called the Jurassic series because it forms the Jura mountains.

The following classification of the beds in that district is the one given by M. Jules Marcou in his *Lettres sur les Roches de Jura, première livraison,* in which I have translated the thicknesses from French metres into English feet. It is remarkable that although the Jura mountains are at least five times the height of the Cotteswold hills, and occupy more than five times the area of the Oolitic range in England, yet the actual thickness of the beds is, according to Marcou's measurements, considerably less in the Jura than it is in England. In the Jura, however, they are wonderfully bent and contorted into folds of every degree of magnitude, so that beds which in some parts at least do not much exceed 1000 feet in thickness, nevertheless make up the principal mass of a large and complicated mountain chain. This chain is composed of no other rocks than the Jurassic and Neocomian beds, and nevertheless far exceeds in height and importance the Palæozoic mountains of England, France, or Germany.

			Feet.
Upper Oolite, 493 ft.	XI. Groupe de Salins.	26. Calcaire de Salins . .	106
		25. Marnes de Salins . .	11
	X. Groupe de Porrentruy.	24. Calcaire de Banné .	132
		23. Marnes de Banné . .	14
	IX. Groupe de Besançon.	22. Calcaire de Besançon	98
		21. Marnes de Besançon .	16
	VIII. Groupe Corallien.	20. Oolite coralliene . .	24
		19. Coral rag de la Chapelle	82
Oxfordian 161 ft.	VII. Oxfordien supérieur.	18. Couches d'Argovie .	98
	VI. Oxfordien inférieur.	17. Marnes Oxfordiennes .	48
		16. Fer de Clucy . . .	16
Lower Oolite, 253 ft.	V. Groupe du département de Doubs.	15. Calcaires de Palente .	20
		14. Calcaires de la Citadelle (Besançon) .	65
		13. Calcaires de la porte de Tarragnoz . .	33
	IV. Groupe du département du Jura.	12. Marnes de Plasne . .	10
		11. Roches de corraux du fort St. André . .	33
		10. Calcaires de la Roche pourrie	59
		9. Fer de la Roche pourrie	33
Lias, 198 ft.	III. Lias Superiéur.	8. Marnes d'Aresche . .	26
		7. Marnes de Pinperdu .	48
		6. Schistes de Boll . .	7
	II. Lias moyen.	5. Marnes de Cernans .	20
		4. Marnes Souabiennes .	43
	I. Lias inférieur.	3. Marnes de Balingen .	38
		2. Calcaires de Blégny .	15
		1. Couches de Schambelen	5
			1100

Of these groups, M. Marcou identifies his Lias with our Lias generally.

He correlates his Oxfordien inferieur with our Oxford clay, believing his Couches d'Argovie to be unrepresented in England, *unless* by Phillips's gradations between the calcareous grits of the Coral Rag and Oxford clay in Yorkshire.

M. Marcou also correlates his Marnes de Banné with the Kimmeridge

clay, and believes his Groupe de Salins to be the purely marine equivalent of the partly marine and partly fresh-water Purbeck beds. He also identifies the intermediate groups of the Jura with the intermediate groups of the English Oolitic series with more or less precision.

M. Marcou gives a table supporting these identifications by lists of characteristic fossils found in most of his twenty-six sub-divisions of the Jurassic series.

France and Germany.—Other authors have adopted different designations for different parts of the Continental Jurassic series, which it will be best perhaps to give in the following tabular form, referring to the table previously given at p 564.

D 12. PURBECK BEDS, not identified by other authors.

D 11. PORTLAND BEDS.—Terrain Portlandien, Upper white Jura, calcaire à tortues de Soleure.

D 10. KIMMERIDGE CLAY.—Terrain Kimméridgien, argiles noirs de Honfleur, calcaire à astartes. Part of the terrain Portlandien of the geologists of the Swiss Jura, who call the lower part Terrain Séquanien ; part of Upper white Jura.

C 9. CORAL RAG.—Terrain Corallien, schistes de Nattheim, calcaire à nérinées. Middle white Jura. (The lithographic flags of Solenhofen are believed to belong to this group.)

C 8. OXFORD CLAY.—Terrain Oxfordien, terrain à chailles, Ornaton thon, Impressa kalk, Spongiten lager. Part of brown Jura and Lower white Jura.

C 8 *a.* KELLOWAY ROCK.—Terrain Callovien, Oxfordien inferieur. Part of brown Jura.

B 5. FULLER'S EARTH ; 6. GREAT OOLITE ; AND, 7. CORNBRASH.—Terrain Bathonien, calcaire de Çaen et Ranville, Parkinsoni Bank. Part of brown Jura.

B 4. INFERIOR OOLITE.—Terrain Bajocien, calcaire Lædonien, calcaire à polypiers, marnes vésuliennes, Eisen-Rogenstein, Discoidien mergel. Middle brown Jura.

A 3. UPPER LIAS.—Terrain Toarcien, Posidonomya schiefer, Jurensis mergel, Opalinus thon. Upper black Jura and Lower brown Jura.

A 2. MARLSTONE.—Terrain Liasien, Amaltheen thon, Numismalen mergel. Middle black Jura.

A 1. LOWER LIAS.—Terrain Sinémurien, grès du Luxembourg, calcaire de Valognes, grès de Lincksfield, Gryphiten kalk. Lower black Jura.

The first-mentioned names in the above list are those of D'Orbigny.

In travelling across France and its borders, within the limits of the Geological Map of France, by E. De Beaumont and Du Fresnoy, the

English geologist cannot fail to be struck with the general resemblance of the Oolitic and Triassic formations to those of his own country. Although it is always unsafe to trust to lithological resemblance, yet it appears certain that there is a wonderful general identity of mineral character in the Mesozoic rocks of western Europe.

When, however, we pass the Jura chain and approach the Alps, the Lias and other Jurassic rocks become completely metamorphosed into clay slates, mica schists, and gneiss, with crystalline limestone (Alpen kalk) like the so-called primary limestones of our old metamorphic districts. The main mass of the Swiss Alps is probably composed of these metamorphosed Oolitic rocks, and it may well be doubted whether any part of the Western Alps shews any but a very few rocks of greater antiquity than the Oolitic Period, although they were at one time supposed to be of primary or "primitive" origin.

America.—Sir C. Lyell describes some of the rocks of North America as like those of the Yorkshire and Sutherland Oolites. They consist of sands and clays, with beds of coal, and contain numerous plants.

Professor W. B. Rogers first described the Richmond coalfield of Virginia, which contains many seams of good coal—one thirty or forty feet in thickness—as belonging to the Oolitic Period. It appears, however, from Marcou's Geology of North America, that the identification of these beds as of Oolitic age is erroneous, and that they are more probably Triassic (Keuper) than Oolitic. Marcou also describes other marine Oolitic beds as existing in New Mexico, and to the west of the Rocky Mountains.

Mr. D. Forbes describes (*Quarterly Journal of the Geological Society*, vol. xvii.) large parts of Peru and Bolivia on the western side of the Andes, as formed of rocks belonging to the Oolitic Period, consisting of clays, shales, and limestones, with many characteristic Oolitic fossils, but interstratified with great beds of porphyry and porphyry-tuffs and conglomerates.

India.—Beds containing Ammonites and other fossils, like those of the Lias and Lower Oolites, were described by Mr. Grant (*Trans. Geol. Soc.*, Lond., vol. v., 2d ser.) as occurring in Cutch, and being associated with other beds containing coal and plants of Oolitic genera.

In the 7th vol. of D'Archiac's *History of the Progress of Geology*, these and other beds in the north of India are spoken of as of marine origin and belonging to the Oolitic Period, and a vast central freshwater formation of Middle and Southern India is also said to belong to the same period.

D'Archiac quotes Mr. Carter's *Summary of the Geology of India* (*Journal of Bombay Branch of As. Soc.*), who says that the Oolitic series of India consists of—

4. Diamond conglomerate.
3. Panna sandstone.
2. Kattra shales, with limestones and coals.
1. Tara sandstone.

1. The Tara sandstone has been called both Old and New Red Sandstone. It is 1000 feet thick and without fossils, but seems to pass up into
2. The Kattra (or Kuttrah) shales, to which, according to Carter, the Burdwan and other coals west of the Hooghly belong, contain plants of the genera Glossopteris, Tæniopteris, Vertebraria, Zamia, etc., etc., together with those of other genera, as Calamites, Pecopteris, Poacites, and Sphenophyllum, which are both Carboniferous and Oolitic genera.
3. The Panna sandstone has a maximum thickness of 2000 feet, and is capped in some places by
4. The Diamond conglomerate, which contains pebbles of sandstone and quartz, and occasionally diamonds.

These two last groups do not contain fossils, but were believed by Newbold to be of præcretaceous age.

Australia.—In a recent exploration on the western coast Mr. Gregory discovered fossils, such as a Trigonia and Ammonite, which seem more like those of the Oolitic series than any others.

This therefore lends some small support to the belief in the Oolitic age of some of the coal-beds of New South Wales, Victoria, and Tasmania, in which plants have been found which were supposed to be necessarily of Oolitic age.*

Arctic Regions.—St. Anjou of the Russian navy asserted many years ago that he had found ammonites in the cliffs of New Siberia, in north latitude 74. Others have since been brought home by Captain Sir

* In vol. i., p. 8, of *Hooker's Himmalayan Journals*, will be found some excellent remarks on the doubtful nature of the evidence as to contemporaneity of beds to be derived from fossil plants, and especially from fossil ferns. He says—"Amongst the many collections of fossil plants that I have examined, there is hardly a specimen belonging to any epoch sufficiently perfect to warrant the assumption that the species to which it belonged can be again recognized. The botanical evidences which geologists too often accept as proofs of specific identity, are such as no botanist would attach any importance to in the investigation of existing plants. The faintest traces assumed to be of vegetable origin are habitually made into genera and species by naturalists ignorant of the structure, affinities, and distribution of living plants."

I would add to this, that geologists proper are not the persons to blame, since they only accept the dicta of the palæontologists, to whom they look as authorities. I entirely agree with another sentence in the pages to which I refer, that "similar fossil plants at places widely different in latitude, and hence in climate, is rather an argument against, than for, their having existed contemporaneously." A rule which, if we admit the doctrine of specific centres, is good for most fossils found in widely separated localities, independently of mere differences of climate.

Leopold M'Clintock from Point Wilkie in Prince Patrick Island, 76° 20′ north. One of these has been called Ammonites M'Clintocki, and compared with Ammonites concavus of the Lower Oolites of France by the Rev. Professor Haughton. Sir L. M'Clintock, Captain Sherrard Osborn, and Sir E. Belcher, also found portions of Ichthyosaurus in those regions. (See appendix to *Fate of Franklin*, by Captain Sir L. M'Clintock. Murray: London, 1859.)

Life of the Period.

The scanty and imperfect traces of life found in the rocks of the Permian and Triassic Periods as assemblages of fossils, are in remarkable contrast with that formed by the abundance of organic remains to be found in the rocks of the Oolitic Period.

The following list will shew some of the generic forms which now appear to have first come into existence on the earth, those that were confined to the period being marked as before by an asterisk.

Plants, *Acrostichites, *Araucarites, *Baiera, *Bensonia, *Brachyphyllum, *Bucklandia, *Cryptomerites, *Ctenis, Cupressus, Cycadeoidea, *Dammarites, *Glossopteris (Sagenopteris) Lonchopteris, *Naiadites, *Pachypteris, *Palæozamia, Peuce, *Phlebopteris, *Podocarya, *Polypodites, *Polystichites, Pterophyllum, *Sagenopteris, *Salicites, *Schizopteris, *Solenites, *Sphæreda, *Sphærococcites, *Stricklandia, Strobilites, *Tæniopteris, *Taxites, Thuytes, *Tympanophora, Zamiostrobus, *Zamites.

Foraminifera, Bulimina, Cristellaria, Flabellina, Marginulina, Nodosaria, Rotalina, Spirolina, Vaginulina, Vulvulina, Webbina.

Spongidæ, Manon, Spongia.

Actinozoa, Adelastræa, *Angeastræa, Anomophyllum, Astrocænia, *Axosmilia, Calamophyllia, Cœlosmilia, *Comoseris, Cyathophora, *Discocyathus, Enallohælia, *Euhelia, Favia, Haplophyllia, *Haplosmilia, Heliastræa, Mæandrina, *Microsolena, Millepora, Oroseris, Pachygyra, *Placosphyllia, Plerastræa, Pleurocœnia, *Phytogyra, *Protoseris, Rhipidogyra, Stephanocœnia, Stylina, Stylosmilia, *Thecocyathus, Thecosmilia, Trochocyathus, Trochosmilia, Ulophyllia.

Polyzoa, Alecto, *Apseudina, *Chrysaora, Cricopora, Idmonea, Terebellaria, Theonoa.

Brachiopoda, Terebratella.

Conchifera, Astarte, *Ceromya, Corbis, *Corbicella, Cyprina, Cyrena, Diceras, Exogyra, *Goniomya, *Gresslya, Gryphæa, Hinnites, *Hippopodium, Isocardia, *Isodonta, Lima, *Limea, Limopsis

Myoconcha, Neæra, Pachyrisma, Pholadomya, Pholas, Potamomya, Quenstedtia, Sphæra, * Tancredia, Thracia, Trigonia,[1] * Unicardium.

Gasteropoda, Actæon, *Actæonina, *Alaria * Brachytrema, Bulla, *Ceritella, Cerithium, Chemnitzia, * Cirrus, Delphinula, * Deslongchampsia, Emarginula, Fissurella, Fusus, Hydrobia, Monodonta, Murex, Nerinæa, Neritina, * Neritopsis, Paludina, Pileolus, Pteroceras, * Purpurina, * Rimula, * Rissoina, Solarium, * Spinigera, Stomatia, * Trochotoma.

Cephalopoda, * Acanthoteuthis, Ammonites,[1] Ancyloceras, Belemnites, * Geoteuthis.

Echinodermata, * Acrosalenia, * Apiocrinus, Astropecten, Cidaris, * Clypeus, Collyrites, * Diplocidaris, Echinobrissus, * Extracrinus, * Galeropygus, * Glypticus, Hemicidaris, * Hemipedina, * Heterocidaris, Holectypus, * Hyboclypus, * Luidia, * Magnotia, * Millericrinus, * Palæocoma, * Pedina, Pentacrinus, * Plumaster, * Polycyphus, Pseudodiadema, Pygaster, Pygurus, Rhabdocidaris, Solaster, * Stomechinus, * Tropidaster.

Annelida, Vermicularia.

Cirrihipedia, Pollicipes.

Crustacea, *Archæoniscus, ?Astacus, * Coleia, Cypridea, Eryon, Estheria, * Glyphæa, * Mecocheirus, ? Pagurus.

Insecta, Berosus, Carabus, Cerylon, Coccinella, Colymbetes, Cyphon, Elater, Gyrinus, Helophorus, Lacophilus, Limnius, Melolontha, Rhyncophora, and many other genera of the families Carabidæ, Blapsidæ, Buprestidæ, Nemoptera, Orthoptera, Homoptera, Diptera, etc., etc.

Fish, Æchmodus, *Amblyurus, *Arthropterus, *Aspidorhyncus, Asteracanthus, Belonostomus, Caturus, * Centrolepis, * Ceramurus, * Chondrosteus, * Conodus, * Cosmolepis, * Ctenolepis, * Cyclarthrus, * Dapedius, * Eugnathus, * Ganodus, Gyrodus, * Gyronchus, * Gyrosteus, Ischyodus, Isodius, * Legnonotus, Lepidotus, * Leptolepis, * Macrosemius, Microdon, * Myriacanthus, * Nothosomus, * Ophiopsis, *Oxygnathus, * Pachycormus, * Pholidophorus, * Pleuropholis, * Pristacanthus, * Ptycholepis, Pycnodus, * Sauropsis, * Scaphodus, * Semionotus, * Sphærodus, Sphenonchus, * Squaloraia, Strophodus, * Tetragonolepis, * Thrissonotus, * Thyellina.

Reptiles, Cetiosaurus, Chelone, Goniopholis, Ichthyosaurus, Lacerta, * Macellodus, * Macrorhyncus, Megalosaurus, * Nothetes, Plesiosaurus, * Pleurosternon, * Pliosaurus, Pterodactylus, * Steneosaurus, Streptospondylus, * Teleosaurus, Tetrosternon, Trionyx.

Mammalia, * Amphitherium (or Thylacotherium), * Amphilestes, * Phascolotherium, * Plagiaulax, * Spalacotherium, * Stereognathus, * Triconodon.

[1] Unless the Trigonia, and the Ammonites, and Belemnites, are to be dated from the Triassic Period from their being found in the Hallstadt and St. Cassian beds.

It will be seen that new genera of plants come in abundantly, and a glance over their names will shew many that have an obvious affinity to still existing genera, such as Araucaria, Dammara, and Zamia, one (Cupressus) being even supposed to belong to an existing genus. Many new ferns (marked by the word *pteris* forming part of the name) supplied the place of those that had died out since the Carboniferous Period.

Of the Foraminifera many of the genera which now came into existence still remain represented by different living species.

Of the Corals, which are, of course, the only kinds of Actinozoa that can occur fossil, none of the genera mentioned above belong to the order Rugosa, the greater number being Aporosa. The whole families Turbinolidæ and Oculinidæ now appear for the first time (*Greene's Cœlenterata*).

The new Polyzoa are more numerous than the new Brachiopoda, of which, indeed, one sub-genus only makes its appearance, the one called Terebratella.

The class Conchifera, however, shews a great number of new genera, more than at any previous period; and many of these still exist as genera, some of them being abundantly represented by different species in the seas of the present day. Others, however, have become extinct more or less completely in intermediate times; while a few, such as Pholadomya and Trigonia are scantily represented by one or two species which appear to be lingering out existence in some remote corners of the globe. Many of the genera which are marked above as being confined to the Oolitic Period have, perhaps, been founded on rather insufficient data, and are, therefore, of rather doubtful value as genera to the biologist, although often useful to the geologist, as grouping together forms more or less distinct from others with which they have an affinity.

The same remarks apply almost equally to the Gasteropods, of which the number of new forms is very great compared with those of the Cephalopods, although the latter class greatly abounded, so far as individuals are concerned. The carnivorous Gasteropods, or those with notches and canals to their mouths, now become much more numerous than heretofore, and must have contributed with the Cephalopods to keep down the superabundance of marine life of other kinds.

The Cephalopods would, if we refer the first appearance of Ammonites and Belemnites to the Triassic Period, have no new generic forms of importance dating from the Oolitic times. So far as the British area, however, and that of western Europe generally, is concerned, we get no Ammonites and Belemnites in præ-Oolitic formations. They certainly now become extraordinarily numerous in individuals. Some of the beds of the Lias, when exposed on the shores of the south coast of England, shew a complete pavement of Belemnites, and in other

places an equal assemblage of Ammonites. Parts of the altered Lias of Portrush, in the north of Ireland, shew these floors of Ammonites of all sizes, from a foot in diameter down to others not bigger than peas. The abundance of species, too, is as great as that of individuals. As many as 600 species of Ammonites have been named, the majority belonging to the Oolitic rocks. Even the minuter subdivisions of this series, as, for instance, the sub-groups of the Upper Lias, viz., the Upper Lias shale and the Upper Lias sands, have each their nine or ten peculiar species of Ammonites.—(*Dr. Wright and Mr. Lycett.*)

As the Ammonites were probably as much oceanic cuttle-fish as is the Nautilus of the present day, and therefore independent of any peculiar character of the sea bottom in which their remains were ultimately preserved, we seem to be driven to the conclusion that the variation in the forms of life apparent in the remains found in these little thin deposits was the result of the extinction and disappearance of one set of species and their replacement by others. If this change took place with no greater rapidity than equal changes take place now (and there is not the slightest evidence in favour of any greater rapidity), each of these little sub-groups of rock must contain the records of myriads of years.

The Belemnites and the other dibranchiate cuttle-fish, the description of which will be found in Mantell's *Medals of Creation* and in Buckland's *Bridgewater Treatise*, are curious, among other things, for the preservation of some of their ink bags. Mr. C. Moore of Bath produced at the meeting of the British Association at Cheltenham, certain nodular lumps of Oolitic rock, which he said he knew from experience contained the remains of these Cephalopods; and, on breaking one of them open, a nucleus of brown dusky powder was seen, that, on being moistened, was instantly used as excellent sepia colour. Dr. Buckland mentions Sir F. Chantry having made a drawing with this fossil sepia.—(*Bridgewater Treatise*, chap. xv.) These squid-like animals must have swarmed in shoals like those which I have seen on the shores of Newfoundland, when the calm surface of the sea looked as if a heavy shower was falling, from the little drops of water ejected from the mouths of myriads of small squids, which were darting about just below the surface, and were sometimes continually visible on each side of the boat as we rowed for miles along shore.

The Echinodermata begin now to lose their abundance of Sea Lillies (Crinoidea), which till now were more abundant than any other order, though a few very beautiful and remarkable new forms of them make their appearance; while among Sea Urchins and Star Fishes the new forms become very numerous, and, as is the case with almost the whole class, singularly elegant. They approach, on the whole, more nearly to those of the present day than did the earlier forms.

The Crustacea, in like manner, begin to resemble our own lobsters, crabs, and shrimps, more nearly than did the older Trilobites and Eurypteridiæ.

A great variety of insects have been found in the Lias and in the Purbeck beds, chiefly by Mr. Brodie, who has published an account of them under the title, "Fossil Insects of the Secondary Rocks;" 1845.

The fossil Fish of the Oolitic rocks are in many places very numerous and often beautifully preserved, the whole skin of glittering scales, with the fins and tail, being sometimes almost as perfect as the skins of recent fish in a museum. Homocercal Fish become now almost as numerous, compared with the heterocercal, as in our own day.

True Sharks and Rays (Squalidæ and Raiadæ) seem now first to have come into existence, in addition to the Cestracionidæ, which existed previously, and are not yet entirely extinct. Most of the Oolitic fish are of the Ganoid order, belonging to the families Pycnodontidæ, Dapedidæ, Lepidotidæ, Leptolepidæ, and Sturionidæ.—(*Owen's Palæontology.*)

Reptiles, which in three preceding periods had been chiefly of the Ganocephalad and Labyrinthodont types of Owen, now become much more numerous and much more various than formerly.

The order Deinosauria (Owen) shews us in the bones of the Megalosaurus a huge hollow-boned* terrestrial reptile, attaining sometimes a length of thirty feet, with great limbs, and rows of sharp, recurved, serrated teeth, a combination of knife, sabre, and saw, with a backward clutch, from which nothing once grasped could have escaped. We may well ask what other large land animals existed, for the destruction of which such a machinery was necessary; and why should it have been necessary, except to keep within bounds the numbers of large vegetable feeders?

The seas that surrounded these lands likewise swarmed with reptile life, the two most remarkable forms being the Ichthyosaurus and the Plesiosaurus. These doubtless preyed on the Fish and Cephalopods, their fellow inhabitants of the deep.

The Ichthyosaurus, figures of whose skeleton will be found in almost all manuals and many other geological works, resembled, as his name denotes, a fish in form, while he retained the essential characters of a saurian reptile. As the whales are mammals adapted for sea life by their external form, with their legs and feet shrunk into paddles, and their tails spread into caudal fins, so the Ichthyosaurus had a caudal fin (although vertical instead of horizontal like the whale's) and his extremities contracted into paddles, and enclosed in a continuous skin, like a mitten, or

* The cast of the inside of a great thigh-bone of this reptile, exhibiting the exact form and ramifications of the marrow, is preserved in the Oxford Museum. It came, however, from the Wealden beds.—(*Buckland's Bridgewater Treatise*, p. 229, 3d Edition.)

glove without fingers. His neck was shrunk, so that his long sharp head projected immediately in front of the thickest part of the trunk, his eyes were very large, protected by a circle of bony plates, and directly under them was the gape of a huge mouth, armed with long rows of conical sharply-pointed teeth, fresh ones to supply the place of those broken or worn out being ever ready to spring from the jaws, which were made of numerous bones "fished" together, so as to unite elasticity and strength. His form must have been something like that of a grampus, only more lithe and slender, while his fish-like vertebræ and tail must have given at once power and velocity to his motions in the waters, of which he must have reigned apparently the unopposable king. Specimens are known in which the orbit of the eye is fourteen inches across, the length of the jaw six feet, and the vertebræ so large that they must have belonged to individuals thirty feet in length. Owen says that he knows thirty species of Ichthyosaurus.—(*Owen's Palæontology.*)

The Plesiosaurus, which, as its name denotes, is more like a saurian and less like a fish than the preceding one, had a smaller body but a much longer neck than it, the neck having no fewer than thirty-three vertebræ, or ten more than the swan. The paddles are longer and narrower than those of the Ichthyosaurus, though resembling them in general structure. The tail is as much shorter as the neck is longer than those of the Ichthyosaurus. It probably basked in the sea-weeds near shore, and darted with its long neck upon its prey, the head being comparatively small, but well-armed with strong teeth. There are twenty species known to Owen.—(*Owen's Palæontology.*) The specimen in the possession of the Royal Zoological Society of Dublin—a very fine one, though not quite perfect—is twenty-three feet in length.

There are in the Lias regular beds of the Copolites or fossil dung of these two animals, shewing the form of the intestinal canal, and often containing fragments of half-digested fish scales, or bones; proving both how numerous they must have been and what great lengths of time must have occasionally elapsed without any deposition on the bed of the sea except that having an organic origin.

There is a sub-genus of Plesiosaurus, called Pliosaurus, with subtrihedral and thicker teeth, and more compressed and flatter cervical vertebræ, which have only been found in the Kimmeridge clay. They seem also to have been thirty or forty feet long.

There are also remains of reptiles called Teleosaurus, resembling the slender-jawed "gavial" of the Ganges and other Crocodilian reptiles living in the earlier part of the Oolitic period, and Chelonian (Turtles and Tortoises) certainly before its close.

Perhaps, however, the most striking of all the forms of animal life which now existed were the Pterodactylia or Flying Lizards, which formed the same external and apparent link between the Reptiles and the

Birds, that the Cheiroptera (or Bats) form between the Birds and the Mammals. The Pterodactyles were true Saurians, with long jaws and sharp teeth, and with four legs and claws, but having the fifth digit of each forepaw enormously elongated, so as to admit of the attachment of a large web of skin stretching from it to the hind leg, and thus make a kind of wing, and give the animals the power of flitting through the air. They may also have been able to swim, as well as to fly. There were several species during the Oolitic Period, none of which, however, seem to have exceeded a cormorant in size, though others much larger appeared subsequently.

The Mammalian remains found in the rocks of the Oolitic series, although they are very rare, are equally interesting with those of reptiles. Most of them seem to have been small carnivorous or insectivorous Marsupials, like the Thylacinus or Myrmecobius of Australia at the present day. The Stereognathus of the Stonesfield slate, however, may, according to Owen, have been a placental mammal, possibly hoofed and herbivorous.—(*Owen's Palæontology.*)

The assemblage of these Marsupial mammals with species of fish like the Cestracion or Port Jackson shark, species of Trigoniæ and Terebratulæ, so like those on the shores of Australia, and species of plants so closely resembling the Australian Zamia, Cycas, and Araucaria, seems to point to a curious analogy between the flora and fauna of Europe and other parts of the world during the Oolitic Period, and those which now flourish in Australia. Is Australia the last home of a peculiar type of vegetable and animal life which once was common to the whole world, but has been elsewhere superseded by new types? This is but one of many equally interesting questions to which future generations of geologists may perhaps be able to give satisfactory answers.

The terrible gap in the series of our geological records between the Carboniferous and Oolitic Periods, which is so imperfectly filled by what is yet known of the Permian and Triassic deposits, prepares us for the statement that no species passes from the preceding periods into the Oolitic, and that even in the genera the contrast is greater than the resemblance.

Extinction of Life during the Period.—The genera, then, which survived from earlier periods and became extinct during the Oolitic, are necessarily few, for many of those which are common to them have survived to still later periods, or till our own time. The following are all that can be included among genera of earlier date now dying out:—

Plants, Calamites,* Cyclopteris, Hymenophyllites, Otopteris, Pecopteris, Sphenopteris.

* According to Sir C. Bunbury, the C. Beanii of Scarborough is a true Calamite.

Brachiopoda, Leptæna, Spirifera—(neither seem to have survived the early part of the period, that in which the Lias was deposited).
Conchifera, Posidonomya,* Cardinia.
Fish, Nemacanthus.

The numerous genera marked with an asterisk at p. 594 shew that while the Oolitic Period was fertile in the production of new generic forms, there were also many consumed during its lapse, and dying out from time to time so as not to survive its close.

This is true also of the species to an equal extent, so that, with the marked exception of the large reptile Megalosaurus Bucklandi and one or two others, no species living during the Oolitic Period is known in any later deposit.

One reason for this is doubtless that a great gap in the marine depositions occurs at the close of the Oolitic Period, which in western Europe ended, as the Cretaceous Period commenced, with a series of fresh-water deposits.

* It is probable that the fossils called Posidonomya in the Oolitic rocks are in reality Crustacea.—(*Cases of Estheria.*)

CHAPTER XXXIV.

CRETACEOUS PERIOD.

THE Cretaceous Period is so called from the Chalk (in Latin, creta) which was formed during a part of this time over a large area now occupied by the European quarter of the globe.

We have just seen that the last deposit that took place in the British area during what has been called the Oolitic Period was of fresh-water origin. The first deposits of the Cretaceous Period within that area, according to the grouping adopted by Sir C. Lyell, were in like manner fresh-water deposits. Professor Phillips groups all these fresh-water deposits together, and includes them in the Oolitic series. Perhaps the best way would be to interpolate another distinct period, between those called Oolitic and Cretaceous, and to include in it the Purbeck, the Wealden, and the Lower Greensand deposits; but this has not yet been attempted, and it might possibly be attended with as many difficulties as the present classification.

TYPICAL ROCK GROUPS.

On both petrological and palæontological grounds it is advisable to separate the rocks formed during this period into two large groups, a Lower and an Upper. They may then be tabulated as follows:—

		Feet.
UPPER CRETACEOUS.	8. Maestricht and Faxoe beds, Pisolitic chalk	100
	7. White chalk, with flints	500
	6. White chalk, without flints	600
	5. Chalk marl	100
	4. Upper greensand	100
	3. Gault	150
LOWER CRETACEOUS.	2. Lower greensand	850
	1. Wealden beds	1300

The groups 6 and 7, forming together the true Chalk, are the most

important and persistent members of the series in Britain. They spread in one unbroken range of high swelling downs across England from Dorchester to the coast of Norfolk, where they are broken through by the broad estuary of the Wash; they re-appear again in Lincolnshire, stretching from the Wash to the Humber, and again in Yorkshire, where they rise into the hills called the Yorkshire Wolds, and terminate in the white cliffs of Flamborough Head.

In Wiltshire and Hampshire this ridge is expanded into the wide undulating upland called Salisbury Plain, from which the chalk spreads towards the east until it separates into two distinct east and west ridges, one called the South Downs running north of Brighton and terminating in Beachy Head, the other called the North Downs running by Guildford and Rochester to Dover and the North and South Forelands.

Another ridge parallel to these starts from Dorchester to Purbeck Hill, and traverses the Isle of Wight from the Needles to Culver Cliffs.

Large outlying patches of Chalk occur to the west of Dorchester, the most westerly being the one at Sidmouth.

It is in the south of England only that the group called No. 1, *The Wealden beds*, is to be found, chiefly in the country between the two ridges just spoken of as the North and South Downs, or to the southward of that which runs through Purbeck and the Isle of Wight.

The following fig., No. 120, represents a section through part of the west coast of the Isle of Wight, where the Cretaceous series and some of the beds above them may all be seen in the space of about a mile.

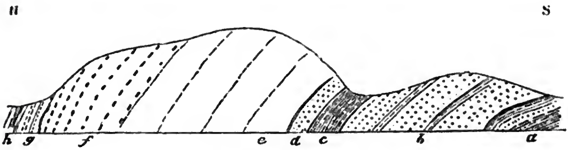


Fig. 120.

Section through Shalcombe Down, on the west coast of the Isle of Wight.

		Feet.
h. London clay	Tertiary rocks.	
g. Plastic clay		
f. Chalk with flints	. . . .	500
e. Chalk without flints	. . . .	1000
d. Upper Greensand	. . . .	100
c. Gault	. . . .	120
b. Lower Greensand	. . . .	800
a. Wealden beds, exposed to a depth of	. . . . . .	400

This section is reduced from sheet 47 of the Hor. Sec. of the G. S., drawn by Mr. Bristow.

A similar section by the same gentleman is given in sheet 56, in a line running through Purbeck Hill, in which the total thickness of the chalk is 1400 feet, and that of the Wealden beds also 1400 feet, the Purbeck beds below them shewing 196 feet.—(See also the margin of *Professor Ramsay's Map of England and Wales.*)

THE LOWER CRETACEOUS ROCKS consist of the Wealden beds and the Lower Greensand.

1. The Wealden beds, so called from their now forming a district known as the Weald of Kent and Sussex, consist of a great series of sandstones and shales, with a few beds of limestone and ironstone occasionally. They are often full of large fragments of drift wood, and of the remains of fresh-water shells, and of some fresh-water and some land animals (reptiles). In general appearance the Wealden rocks not unfrequently resemble some of the Coal-measures of the true Carboniferous Period.

These beds look like a fossil delta formed at the mouth of some great river, which brought down the sweepings of a great tract of dry land to the area lying between Purbeck and Boulogne.

The Wealden rocks are commonly divided into two groups—

	Feet.
b. The Weald clay	280
a. The Hastings sand	1000

These distinctions, however, seem hardly to be carried out by any precise line of demarcation. The lower beds are more arenaceous, and the upper more argillaceous; but great beds of clay occur interstratified with the Hastings sands, and beds of sand with the Weald clay. It is probable that these beds change their character laterally as well as vertically, great banks of sand and large deposits of mud having been formed side by side. The sandstones are sometimes impregnated with carbonate of lime, so as to become calcareous grits, and small beds of limestone (forming Petworth or Sussex marble), chiefly consisting of fresh-water snail shells (Paludina) occur here and there in the clay. Local names were given by Dr. Mantell to the different parts of the Wealden series in different places, as Ashburnham beds, Worth sands, Tilgate beds, Horsham beds, etc., the Ashburnham beds being the lowest of the series.

Mr. Drew, of the Geological Survey, has lately described (*Q. J. Geol. Soc.*, vol. xvii.) with more precision the upper part of the formation as it exists around Tunbridge Wells. His classification is as follows :—

	Feet.
4. Weald clay, with some beds of stone, 10 feet thick near Horsham and hence called Horsham stone, lying about 120 feet above the base of the clay . .	600

		Feet.
3.	Tunbridge Wells sand, with a bed of clay called Grinsted clay, 50 feet thick, coming in towards the west between the Upper sand above and the Rock sand below .	200
2.	Wadhurst clay, with one or two little beds of sand, a shelly limestone formed of Cyrena, and a band of clay ironstone, once largely used for iron ore . . .	100
1.	Ashdown sand, like the Tunbridge Wells sand, and containing subordinate beds of clay and ironstone ; base not seen, but having a thickness of upwards of .	250

Characteristic Fossils of the Wealden Beds.

Plants.

Clathraria Lyellii . .	Mantell's Meds., ch. vi.
Endogenites erosa . .	Foss. gr. 34, *a*.
Equisetum Lyellii . .	Mantell's Meds., fig. 12.
Lonchopteris Mantellii .	Geol. Tr. vol. i., 2d ser.
Sphenopteris gracilis .	Ly. Man., fig. 312.
Thuytes Kurrianus .	Mantell's Meds., fig. 62.

Conchifera.

Cyrena major . .	Geol. Tr. vol. iv., 2d ser.
Cyrena media . .	Foss. gr. 34, *b*.
Mytilus Lyellii . .	Geol. Tr. vol. iv., 2d ser.
Unio Valdensis . .	Tab. V. and Ly. Man. fig. 309.
Unio Mantellii . .	Foss. gr. 34, *c*.

Gasteropoda.

Cerithium carbonarium.	
Melanopsis tricarinata .	Geol. Tr. vol. iv., 2d ser.
Neritina Fittoni . .	*Ibid.*
Paludina fluviorum . .	Foss. gr. 34, *d*.
——— Sussexiensis .	Tab. View.

Crustacea.

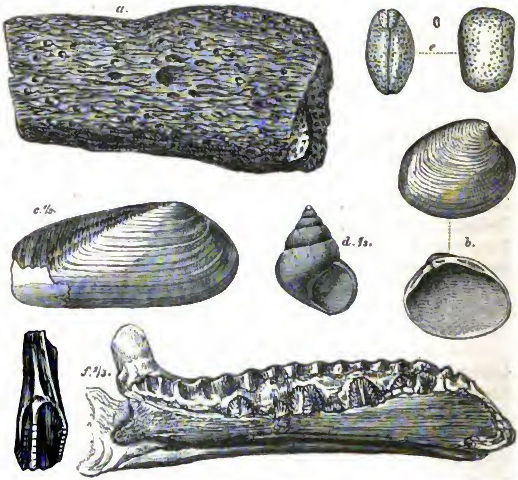
Cypridea Valdensis . .	Foss. gr. 34, *e* (magnified).
Estheria membranacea .	Sow. M. C., 527.

Fish.

Gyrodus Mantellii . .	Agassiz.
Lepidotus Fittoni . .	Agassiz.
Pycnodus Mantellii .	Agassiz.

Reptiles.

Cetiosaurus brevis	.	Mantell's Til. foss.,* t. 9.
Chelone Bellii	.	Mantell's Meds., fig. 240.
† Hylæosaurus Owenii	.	Mantell's Wond.,* 7th ed.



Fossil Group No. 34.
Wealden Fossils.

a. Endogenites erosa.
b. Cyrena media.
c. Unio Mantellii.
d. Paludina fluviorum.
e. Cypridea Valdensis.
f. Iguanodon Mantellii.

Iguanodon Mantellii	.	Mantell's Meds., ch. xvii.
Pterodactylus Cliftii	.	*Ibid.* Til. foss.
Streptospondylus major	.	Ow. Brit. Ass. Rep.
Tretosternon Bakevellii	.	Mantell's Meds., fig. 241.

Birds.

Palæornis Cliftii.

* Dr. Mantell's Tilgate Fossils, and Wonders of Geology.
† See also Owen's Palæontology, and Buckland's Bridgewater Treatise.

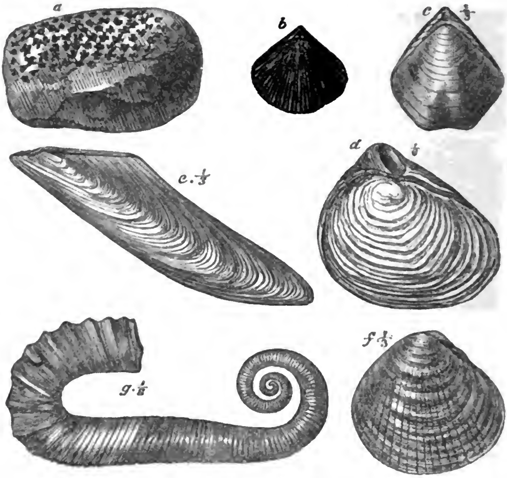
2. *The Lower Greensand* is best seen at Atherfield and other places in the Isle of Wight, and at Hythe and other parts of the coast of Kent. It there consists of alternations of sands, sandstones, and clays, with occasional calcareous bands. The calcareous sandstones sometimes form hard bands, known as Kentish Rag; the clays are sometimes excellent fullers' earth, 60 feet in thickness, and are most abundant in the lower part of the formation, the upper being almost entirely sands. The general colour is dark brown, sometimes red, and the sands are often bound together by an abundance of oxide of iron, from which the formation was formerly called Iron Sand. It has also been called Shanklin Sand from a place in the Isle of Wight. It derives its name of Greensand from the occurrence of a number of little dark green specks (silicate of iron) which are sometimes so abundant as to give a greenish tinge to some of the beds; but the term "green" is generally quite inapplicable as a *description*, though it still remains as a commonly received *name*. The whole formation in Britain is very various in character. Its maximum thickness is 843 feet.

The beds immediately above the Wealden shew sometimes a sort of passage lithologically, as if partly made up of those below, while the fossils are quite distinct, being entirely marine. It appears that a depression had taken place and allowed the sea to flow over the area which had been previously covered with fresh water. The change may thus be one of conditions rather than one of great lapse of time—a supposition strengthened by the fact of the bones of the Iguanodon Mantellii being found in the Lower Greensand, shewing that the great reptile still lived on some neighbouring land, and that an occasional carcass of it was swept out to sea.

Characteristic Fossils of the Lower Greensand.

Plants.	
Abietites Benstedi . . .	Q. J. G. S., vol. ii.
Actinozoa.	
Holocystis elegans . . .	Foss. gr. 35, *a*.
Brachiopoda.	
Rhynchonella Gibbsii . . .	Foss. gr. 35, *b*.
Terebratula sella . . .	Foss. gr. 35, *c*.
Conchifera.	
Astarte Beaumontii.	
Cardium sphæroidium . . .	Q. J. G. S., vol. i.
Cucullæa costellata . . .	Sow. M. C., 447.

Cytheræa parva	Sow. M. C. 518.
Exogyra sinuata	Foss. gr. 35, *d.*
Gervillia anceps	Foss. gr. 35, *e.*
Myacites mandibula	Sow. M. C. 43.



Fossil Group No. 35.
Lower Greensand Fossils.

a. Holocystis elegans.
b. Rhynchonella Gibbsii.
c. Terebratula sella.
d. Exogyra sinuata.
e. Gervillia anceps.
f. Sphæra corrugata.
g. Ancyloceras gigas.

Perna Mulleti	Tab. V. and Ly. Man., fig. 296.
Requienia (Diceras) Lonsdaleii	Tab. View.
Sphæra corrugata . . .	Foss. gr. 35, *f.*
Thetis minor	Tab. View.
Trigonia dædalia	Sow. M. C. 88.
——— caudata . . .	Tab. V. and Phil. Man., fig. 286.

Gasteropoda.

Pleurotomaria gigantea	Geol. Tr. vol. iv., 2d ser.
Pteroceras Fittoni	Tab. View.

Cephalopoda.

Ammonites Martini	Tab. View.
Ancyloceras (Scaphites) gigas . .	Foss. gr. 35, *g*.
Belemnites dilatatus . . .	Mantell's Med., fig. 141.
Crioceras Duvalii.	
Nautilus plicatus	Tab. View.

Echinodermata.

Cardiaster Benstedi . . .	M. G. S., Dec. 4.
Hemipneustes Fittoni . . .	*Ibid.*
Salenia punctata	Tab. View.

Crustacea.

Meyeria Vectensis	Mantell's Wonders, fig. 73.

Reptiles.

Protemys serrata	Owen. Br. Foss. Rept.

The Upper Cretaceous Rocks.

3. Gault.—This is a stiff dark gray, blue, or brown clay, often used for brick-making. It can be seen very well at Cambridge and at Folkestone, and at various places below the escarpments of the North and South Downs in the Wealden district, as in the neighbourhood of Reigate for instance. It is not known anywhere to the north of Cambridgeshire, unless it forms part of the Speeton clay of Yorkshire. The fossils in it are often beautifully preserved, as in other similar clays, having been well packed and protected from atmospheric or other influences.

Characteristic Fossils of the Gault.

Foraminifera.

Rotalina caracolla.

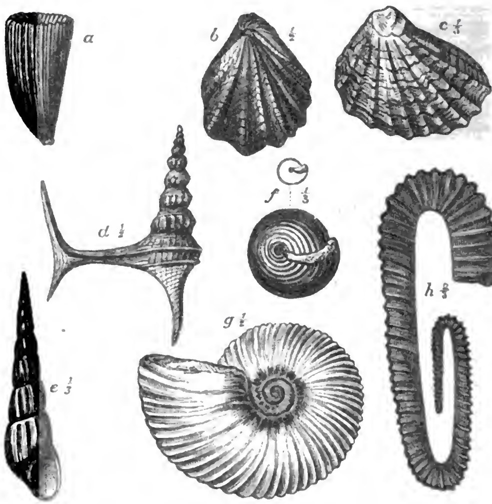
Actinozoa.

Cyathina Bowerbankii . .	Br. Foss. Cor.
Cyclocyathus Fittoni . . .	Tab. View.
Trochocyathus conulus . .	Foss. gr. 36, *a*.
Trochosmilia sulcata . . .	Br. Foss. Cor.

Conchifera.

Inoceramus concentricus . .	Tab. View.
——— sulcatus . .	Foss. gr. 36, *b*.

Nucula pectinata	. . .	Tab. View.
Plicatula pectinoides	. . .	Foss. gr. 36, *c*.



Fossil Group No. 36.

Gault Fossils.

a. Trochocyathus conulus.
b. Inoceramus sulcatus.
c. Plicatula pectinoides.
d. Rostellaria carinata.
e. Scalaria Gaultina.
f. Bellerophina minuta.
g. Ammonites splendens.
h. Hamites attenuatus.

Gasteropoda.

Dentalium ellipticum	. . .	Tab. View.
Natica Gaultina	. . .	Tab. View.
Rostellaria carinata	. . .	Foss. gr. 36, *d*.
Scalaria Gaultina	. . .	Foss. gr. 36, *e*.
Solarium conoideum	. . .	Tab. View.

Pteropoda.

Bellerophina minuta	. . .	Foss. gr. 36, *f*.

Cephalopoda.

Ammonites dentatus . . .	Tab. View.
——— lautus . . .	Tab. View.
——— interruptus . .	Tab. View.
——— splendens . .	Foss. gr. 36, *g*.
——— varicosus . .	Tab. View.
Belemnites minimus . . .	Tab. View.
Hamites intermedius . . .	Foss. gr. 36, *h*.
——— spiniger . . .	Ly. Man., fig. 291.
Helicoceras (Hamites) rotundus .	Tab. View.

Echinodermata.

Hemiaster Bailyi . . .	M. G. S., Dec. 5.
Pentacrinus Fittoni . . .	Geol. Tr., vol. iv.

Annelida.

Serpula articulata . . .	Sow. M. C., 599.

Crustacea.

Notopocorystes Bechei.	
——— Stokesii . .	Tab. V., and Mant. Med., fig. 168.

4. Upper Greensand.—This set of beds often resembles the Lower Greensand in lithological character, but the same caution is to be used in taking its designation for a *name* only and not for a *description*, as the sands are by no means always green, and other sands, especially some Tertiary sands, are to be found quite as green, or greener, than those which have received the name of Greensand. Beds and concretionary masses of calcareous grit occur in it, sometimes called Firestone, sometimes Malm rock. Concretions, probably coprolitic, containing phosphate of lime, also occur, and are valuable to the agriculturist. It has been surmised that the Upper Greensand may be in part a shore deposit, and therefore contemporaneous with, rather than preceding, the lowest beds of the chalk, but wherever the two are together, we always find the Upper Greensand underneath the Chalk Marl. In Cambridgeshire the Upper Greensand is often not more than three feet thick, but it thickens towards the west and south, and in Wiltshire and the Isle of Wight is over 100 feet.

Characteristic Fossils of the Upper Greensand.

Spongidæ.

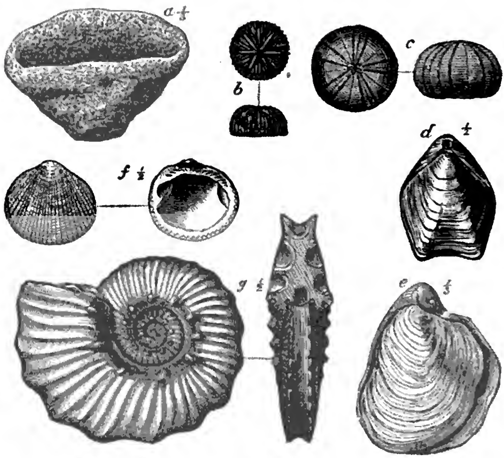
Chenendopora fungiformis . .	Foss. gr. 37, *a*.
Siphonia pyriformis . . .	Tab. V. and Ly. Man., 286.
Verticillites anastomosans . .	Mant. Med., fig. 70.

Actinozoa.

Micrabacia coronula	Foss. gr. 37, *b*.
Parastræa stricta	Br. Foss. Cor.

Brachiopoda.

Rhynchonella latissima	Dav. Cr. Brach.
Terebratella pectita	Tab. View.
Terebratula biplicata	Foss. gr. 37, *d*.
Trigonosemus lyra	Ly. Man., fig. 289.



Fossil Group No. 37.
Upper Greensand Fossils.

a. Chenendopora fungiformis.
b. Micrabacia coronula.
c. Echinus granulosus.
d. Terebratula biplicata.
e. Exogyra columba.
f. Pectunculus sublævis.
g. Ammonites auritus.

*Conchifera.**

Arca carinata	Sow. M. C., 44.
Cardium Hillanum	Tab. View.
Cucullæa fibrosa	Tab View.
Exogyra columba	Foss. gr. 37, *e*.

* Some new species of Conchifera and Echinodermata have lately been described by Mr. Harry Seeley, from the Upper Greensand near Cambridge.

Gryphæa vesiculosa	Sow. M. C., 369.
Pecten quinquecostatus	Tab. View.
Pectunculus sublævis	Foss. gr. 37, *f*.
Thetis major	Sow. M. S., 513.
Trigonia dædalia	Tab. View.

Gasteropoda.

Actæon affinis	Tab. View.
Natica Gentii	Sow. M. C. 54.
Turritella granulata	Tab. View.

Cephalopoda.

Ammonites auritus	Foss. gr. 37, *g*.
—— rostratus	Sow. M. C., 173.

Echinodermata.

Catopygus carinatus	M. G. S., Dec. 1.
Diadema Bennettiæ	*Ibid.*, Dec. 5.
Discoidea subuculus	*Ibid.*, Dec. 1.
Echinus granulosus	Foss. gr. 37, *c*.
Salenia personata	Tab. View.

Annelida.

Vermicularia concava	Tab. View.

Reptiles.

Professor Sedgwick at the meeting of the British Association at Oxford gave an account of the wonderful reptilian remains that had been lately discovered in the little seam of the Upper Greensand at Cambridge, and of their determination, by Professor Owen. There were remains of Dinosaurians analogous to the Iguanodon, of Teleosaurus, Ichthyosaurus, 2 or 3; Plesiosaurus, 6 or 8; Polyptichodon; and 5 specimens of Pterodactyle, varying in size from that of a pigeon or Madagascar bat, up to one with a spread of wing 25 feet across. There were also 8 or 10 Turtles, large and small.

Birds.

In addition to these, the bones of two species of birds had been discovered, which must have been about the size of a pigeon.

The Chalk Proper. Over the beds thus described extends the great formation of the true chalk, the subdivisions of which may be thus described:—

5. Chalk Marl. The top of the Upper Greensand becomes argillaceous, and passes upwards into a pale buff-coloured marl or argillaceous

limestone, sometimes of sufficient consistency to be used as a building stone. This in its higher portion begins to lose the argillaceous character, and gradually passes into the soft white pulverulent limestone familiar to every one as chalk.

6. WHITE CHALK WITHOUT FLINTS. This is a great mass of soft and often pulverulent limestone, thick bedded, the stratification often obscure, partly from the obliteration of the bedding planes, partly from the abundance of quadrangular and diagonal joints, the surfaces of which are often weather-stained, dirty green, or yellow. Nodular balls of iron pyrites, radiated internally, are frequent in it, and produce rusty stains about the rock.

7. WHITE CHALK WITH FLINTS. There are no lithological distinctions between the Lower and Upper Chalk, except the occurrence in the latter of rows of nodules of back flint, and occasionally of seams and layers of the same substance. These occur either along the planes of stratification or parallel to them, so that they point clearly out the original bedding of the rock.

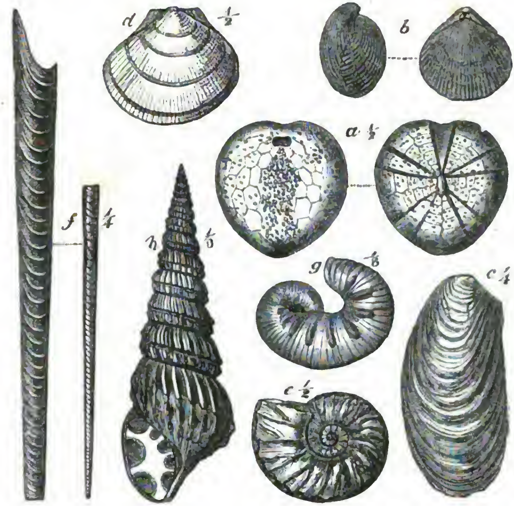
It is rare to find, either in the Upper or Lower Chalk, anything but pure limestone or pure flint. Little pebbles, however, sometimes occur in it, probably carried by the roots of plants ; and in a cliff a little east of Dieppe, I once observed in the heart of the Upper Chalk, a little band, about 8 inches thick and 20 feet long, of brown clay or marl, perfectly interstratified with the Chalk, and not, as it seemed to me, connected with any pit holes, by which it could have been swept in from the surface. Mr. Godwin Austen has described the occurrence of a large boulder of granite, apparently of Scandinavian origin, which was found in the Chalk near Croydon, and other extraneous fragments both there and elsewhere.—(*Q. J. Geol. Soc.*, vol. xiv.)

Although the Chalk and the Carboniferous Limestone are so different in texture and induration, there is yet a certain resemblance in the forms of the country they produce. Their hills have equally broad undulating grassy downs, the escarpments of which are quite smooth in the chalk, while they are notched into steps in the mountain limestone. Their valleys are equally marked by scaurs, and tors and pinnacles, as any one may see by comparing the forms of the rocks on the sides of the valley of the Seine with those in the valleys of Derbyshire. The forms are, of course, bolder, larger, and more durable, in the latter than the former.

Characteristic Fossils of the Chalk.—These are very numerous, certain forms being found more or less common throughout the Chalk, and several being common to the whole Upper Cretaceous series, from the Gault to the Upper Chalk.

It appears that it is possible to select two lists of fossils, one set

being either peculiar to the lower part of the chalk, or most abundant in it; the other set being equally confined to, or most common in, the upper part of it. It appears, however, to me, to be the best for the sake of reference, to unite the two lists with which Mr. Baily has supplied me, appending to each species a U. for the Upper Chalk, L. for the Lower Chalk, and M. for the Chalk Marl.



Fossil Group No. 38.
Lower Chalk Fossils.

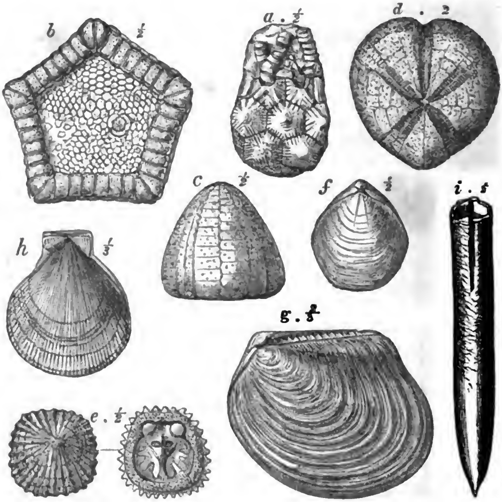
a. Ananchytes subglobosus.
b. Rhynchonella Cuvieri.
c. Inoceramus mytiloides.
d. Lima Hoperi.
e. Ammonites varians.
f. Baculites anceps.
g. Scaphites equalis.
h. Turrilites costatus.

Spongidæ.

U. Choanites Königi.	Tab. V. and Mant. Med. fig. 75.
U. Ventriculites decurrens	Tab. V. and Ly. Man. fig. 284.
U. ——— radiatus	Mant. Med. fig. 81.

Foraminifera.

U. Bulimina obliqua.
U. Cristellaria rotulata . . . . . Mant. Med. fig. 109.
U. Dentalina gracilis.
U. Rotalina ornata.



Fossil Group No. 39.
Upper Chalk Fossils.

a. Marsupites ornatus.
b. Goniaster Parkinsoni.
c. Galerites albogalerus.
d. Micraster coranguinum.
e. Crania Ignaburgensis.
f. Terebratula carnea.
g. Inoceramus Lamarckii.
h. Pecten nitidus.
i. Belemnitella mucronata.

Actinozoa.

U. Cœlosmilia laxa . . . Brit. Foss. Cor.
L. Stephanophyllia Bowerbankii . *Ibid.*

Polyzoa.

U. Heteropora cryptopora.
U. Lunulites cretaceus . . . Mant. Med. cut 70, fig. 1.

Brachiopoda.

U. Crania Ignabergensis . .	Foss. gr. 39, *e*.
U. —— Parisiensis . . .	Tab. View.
U. Magas pumila . . .	Tab. V. and Ly. Man. 266.
L. Rhynchonella Cuvieri . .	Foss. gr. 38, *b*.
U. —— octoplicata . . .	Tab. V. and Ly. Man. 265.
U. Terebratula carnea . .	Foss. gr. 39, *f*.
U. Terebratulina striata . .	Dav. Brach.

Conchifera.

U. Exogyra conica . . .	Sow. M. C. 605.
U. Inoceramus Brongniarti .	*Ibid.* 441.
U. —— Lamarckii . . .	Foss. gr. 39, *g*.
L. —— mytiloides . . .	Foss. gr. 38, *c*.
L. Lima Hoperi . . .	Foss. gr. 38, *d*.
L. Ostræa frons . . .	Sow. M. C., 365
U. —— vesicularis . . .	Ly. Man. fig. 275.
L. Pecten Beaveri . . .	Ly. Man. fig. 270.
U. —— nitidus . . .	Foss. gr. 39, *h*.
L. Plicatula inflata . . .	Sow. M. C. 409.
L. Pholadomya decussata . .	Phil. G. Y. t. 2.
U. Spondylus (Plagiostoma) spinosus	Tab. View.

Gasteropoda.

L. Avellana cassis . . .	D'Orbigny.
L. Phorus canaliculatus . .	*Ibid.*
U. Pleurotomaria perspectiva .	Sow. M. C. 428.

Cephalopoda.

L. Ammonites complanatus .	Sow. M. C. 94.
M. —— Rothamagensis . .	Ly. Man. fig. 290.
L. —— varians . . .	Foss. gr. 38, *e*.
L. Baculites anceps . . .	Foss. gr. 38, *f*.
U. Belemnitella mucronata .	Foss. gr. 39, *i*.
L. —— plena	Sharpe, Chalk Moll.*
L. Hamites simplex . . .	D'Orbigny.
L. Nautilus elegans . . .	Mant. Med. fig. 151.
L. Scaphites equalis . . .	Foss. gr. 38, *g*.
L. Turrilites costatus . .	Foss. gr. 38, *h*.

Echinodermata.

U. Ananchytes ovatus . .	Tab. V. and Mant. Med. fig. 104.

* Chalk Mollusca by D. Sharpe, Pal. Soc.

L. Ananchytes subglobosus . .	Foss. gr. 38, *a.*
U. Bourgueticrinus ellipticus . .	Dix. Foss. Suss.*
U. Cardiaster granulosus . . .	Tab. View.
U. Cidaris perornata . . .	Dix. Foss. Suss.
L. Discoidea cylindrica . . .	Mem. G. S., Dec. 1.
U. Galerites albogalerus . . .	Foss. gr. 39, *c.*
U. Goniaster Parkinsoni . . .	Foss. gr. 39, *b.*
U. Marsupites ornatus . . .	Foss. gr. 39, *a.*
U. Micraster coranguinum . .	Foss. gr. 39, *a.*
L. Salenia Austeni . . .	M. G. S., Dec. 5.

Annelida.

L. Serpula amphisbœna . . .	Goldfuss.

Crustacea.

L. Enoploclytia Sussexiensis . .	Mant. Med., fig. 169.

Fish.

U. Beryx Lewesiensis . . .	Mantell's Wond., fig. 83.
U. Lamna acuminata . . .	Dix. Foss. Suss.
U. Macropoma Mantellii . . .	Mantell's Wond., fig. 80.
U. Osmeroides Lewesiensis . .	Mantell's Wond., fig. 79.
U. Otodus appendiculatus . .	Dix. Foss. Suss.
L. Ptychodus decurrens . . .	Ly. Man., fig. 287.

Reptiles.

L. Chelone Benstedi . . .	Mant. Med., fig. 238.
L. Dolichosaurus longicollus . .	Dix. Foss. Suss.
L. Ichthyosaurus campylodon . .	*Ibid.*
U. Mosasaurus gracilis . . .	Mant. Med., ch. xvii.
L. Plesiosaurus Bernardi . .	Dix. Foss. Suss.
L. Polyptychodon interruptus . .	*Ibid.*
L. Pterodactylus Cuvieri . .	Ow. Br. Foss. Rep.

There are in Britain† no beds containing chalk fossils, or in any way belonging to the chalk, lying above the true chalk with flints.

8. Maestricht or Pisolitic Chalk. In parts of the North of France, however, there occur curious banks of a white pisolitic limestone, resting apparently in hollows of the chalk, not always on exactly

* Dixon's Fossils of Sussex.

† It was stated at the meeting of the British Association at Oxford that near Norwich beds occurred like the Maestricht chalk. It was also said that a boring had been put down there 800 feet in the Chalk with flints, without piercing through into the Chalk without flints.

the upper portion of it, and being therefore apparently slightly unconformable to it. It occurs also sometimes on the same level as the lower beds of the Tertiary rocks about it. The fossils are rather peculiar, but some of them are true Cretaceous, while none I believe are Tertiary forms.

Near Maestricht, in Holland, also, the chalk with flints (No. 7) is covered by a kind of chalky rock with gray flints, over which are some loose yellowish limestones, without flints, and being sometimes almost made up of fossils.

Similar beds, containing some of the same fossils, occur also at Faxoe in Denmark.

Characteristic Fossils.—Together with several true Cretaceous fossils, such as Pecten quadricostatus, Belemnites mucronatus, Terebratula carnea, etc., these beds contain species of the genera Voluta, Fasciolaria, Cypræa, Oliva, Mitra, Cerithium, Fusus, Trochus, Patella, Emarginula, etc., several of which genera are elsewhere found in Tertiary rocks only.

In the beds near Maestricht, the head of a large lacertilian reptile was formerly discovered, which received the name of Mosasaurus Hofmanni (*Mantell's Meds.*, fig. 227), of which the head alone is more than three feet long.—(*Owen's Palæontology*, p. 279.)

Outlying English Deposits.—There are some outlying deposits in different parts of England, respecting which there are some doubts as to their exact place in the series.

The Speeton Clay of Yorkshire rests upon the Coralline Oolite, with a very thin band of what might be Kimmeridge clay at the bottom. Professor E. Forbes believed that it belonged to the Lower Greensand; Professor Phillips classes it with the Gault. It has a set of fossils peculiar to itself, and one, *Exogyra minuta*, common to it and the Lower Greensand. If, however, this Speeton clay really belongs to the Lower Cretaceous group, it forms a marked exception to the otherwise general fact that that group is absent in Yorkshire. On the other hand, the Upper Cretaceous series, commencing there with the Red Chalk band, overlaps the Speeton clay unconformably, as it does all the lower beds, concealing in one part even the whole Oolitic series down to the Lias.

The Greensands of Black Down in Devonshire include a mixture of fossils which elsewhere are confined to the Lower Greensand, the Gault, and the Upper Greensand.

There are also sands and gravels near Farringdon in Wiltshire, in which Lower Greensand fossils are mingled with others belonging to Upper Cretaceous rocks. As these beds are not covered by any other rock, Mr. Daniel Sharpe suggested the possibility of their being gravel (drift, or shore deposits) of a later date than the Chalk itself, yet belonging to the Cretaceous Period, and that the fossils had been washed out

of the different beds. They are considered, however, by the Geological Survey to belong to the Lower Greensand, as are also the fresh-water iron sands capping Shotover Hill near Oxford, though it is possible that these may belong to the Wealden beds.—(*See Mems. Geol. Survey description of sheet* 13; *and also Prof. Phillips in Q. J. Geol. Soc.*, vol. xiv., p. 236.)

The Red Chalk at the base of the White Chalk of Norfolk, Lincoln, and Yorkshire, in which latter locality it rests unconformably on the Speeton clay, is peculiar, not only from its lithological character, but from containing some peculiar fossils along with others that range from the Gault into the Chalk. Mr. H. Seely, in a paper in the *Annals and Magazine of Natural History* for April 1861, supports the supposition of its being a part of the Upper Greensand, which is not otherwise represented north of Cambridge.

The existence of local groups of rock, however, that will not exactly fit into the general series, either from their containing fossils different from those found in any other group, or from their uniting parts of two sets of fossils which are elsewhere distinct—although sometimes perplexing—seems to me neither unnatural nor different from what might be expected. It merely shews us that which has been often before insisted on, namely, that our series is a series of fragments, and not one of absolutely continuous succession. The intervals between beds have been often very great, those between formations incalculable, the local deposits formed here and there in these intervals will, of course, often have characteristics different from, or intermediate between, the preceding and following groups.

Lie and Position of the Cretaceous Rocks in England.—There is yet another cause for uncertainty in the exact determination of the date of some of the deposits at the base of the Cretaceous series in different parts of England, and that is, that they are always more or less unconformable to the Oolitic rocks below. A surface of erosion was formed upon the Oolitic rocks before the deposition of the Cretaceous beds, thus producing irregularities in the nature and thickness of the latter, as well as gaps in the series. According to Professor Phillips, erosion is apparent in Oxfordshire in the Oolitic series itself, since he attributes the absence of the upper part of the Coralline Oolite there to its erosion, before the deposition of the Kimmeridge clay, and it has long been known that from Oxfordshire, towards the north-east, the Oolitic beds, from the Oxford clay upwards, are successively overlapped by the Lower Cretaceous beds. The occurrence of a little bank of Coral rag near Upware, between Cambridge and Ely, makes the former continuity of that formation probable.

When we get into Yorkshire, we know that the Chalk itself rests on the Lias, owing apparently to a local elevation of the Oolitic beds

above the sea, and their consequent denudation before the deposition of any of the Cretaceous series, as shewn in Phillips's section to his paper on the Oolites of Yorkshire.—(*Q. J. Geol. Soc.*, vol. xiv.)

The proof of elevation and denudation having taken place in the Oolites before the deposition of the Cretaceous series, is interesting when taken in connection with the fact that at Harwich, Kentish Town, and Calais, deep borings put down in search of water have, after passing through the Cretaceous series, come down, not into Oolitic rocks, but into others apparently of Palæozoic age. At Harwich they found a black slate at a depth of about 1025 feet, just below the base of the Gault. At Kentish Town they reached the base of the Gault at 1113 feet, and then passed through 188 feet of red rocks, clays, sandstone, and conglomerates, some of which appeared to me very like the trappean breccia of the Permian rocks of the Midland Counties.—(See papers by J. Prestwich, *Q. J. Geol. Soc.*, vols. xii. and xiv.) At Calais, the Chalk was pierced, and rocks identified as true Coal-measures were reached at the depth of 1100 feet. On following the nearly horizontal Chalk into the north of France and Belgium, the Carboniferous and other Palæozoic rocks in a highly contorted state come out from underneath it, having suffered vastly from the denudation which produced the surface on which the Cretaceous rocks were deposited.

Drawing a conclusion from these facts, Mr. Godwin Austen, before the boring of the wells at London and Harwich, suggested the probability of a ridge of Carboniferous and other Palæozoic rocks extending at no great depth from the Ardennes and the Eifel on the east, to the neighbourhood of Bristol, Somerset, and Devon on the west, this old ridge being overlaid unconformably by the Mesozoic rocks—the Triassic, the Oolitic, and the Cretaceous deposits successively overlapping each other from west to east, as the old Palæozoic land became successively submerged in that direction.—(*Austen on Possible Extension of Coal-measures beneath south-east of England. Q. J. Geol. Soc.*, vol. xii.)

It is not improbable that the anticlinal of the Weald and Salisbury plain, and the synclinal of the Hampshire basin, with its sharp uniclinal curve running through the Isles of Wight and Purbeck, may be referable to some features in the old surface below, producing an effect upon the newer rocks above them, when they were all subsequently acted on by disturbing forces, re-directed perhaps into the old east and west lines along which they had acted at the close of the Palæozoic period.

Ireland.—In the county Antrim and its borders, Chalk with flints occurs with a maximum thickness of about 200 feet. It lies horizontally near the top of the hills, just west of Belfast, and spreads in horizontal sheets over the whole county, but is generally covered by an immense capping of basaltic rocks, so as only to shew itself round the

edge of the basalt, or as outliers on the top of some of the adjacent hills. (See fig. 122.) It is called in Ireland White Limestone, as the stone is considerably harder and firmer than the friable rock which is commonly known as Chalk. It contains an abundance of fossils of the same species as those found in the Chalk of England, but also others in addition, especially a number of univalve shells.

Mr. Sharpe in the publications of the Palæontographical Society, describes four species of Ammonites as peculiar to the north of Ireland, and one as common to it and the north of France. He believes it to be contemporaneous with the Upper Chalk. It rests, however, conformably on, and seems to pass down into a pale sandy stone, mottled with green specks, which becomes a loose, dark, green sand below, and is known in the country by the name of Mulatto stone. This is never more than about twenty feet thick. It is full of Exogyra and other fossils of the Upper Greensand, so that if the White Limestone above it be the Upper Chalk, the Lower Chalk must be absent.

The Greensand rests directly on thirty feet of black shales with Lias fossils, and that on the Red Marls of the Trias. (See section, fig. 122.)

Switzerland.—The Cretaceous series as now described spreads over a large part of western Europe.

The Wealden beds may be seen at Boulogne, with much the same characters as they have in the Isle of Wight. As, however, they are of fresh-water origin, we should expect to meet somewhere with their contemporaneous marine deposits. M. Thurman formerly described beds in the neighbourhood of Neufchatel in Switzerland, which are probably the marine equivalents of the Wealden beds. They have since been called Neocomian, from the Latinised name of the Swiss town.

M. Marcou (in his *Letters sur les Roches de Jura*) gives the following tabular account of these beds, and of what he believes to be their English equivalents :—

	Switzerland.	*England.*
UPPER NEOCOMIAN.	6. White limestones. 5. Limestones with green grains.	Lower Greensand (the bottom part of it).
MIDDLE NEOCOMIAN.	4. Marls of Hauterive. 3 Yellow Limestone.	Weald Clay and Hastings Sand.
LOWER NEOCOMIAN.	2. Limonite. 1. Blue marls unfossiliferous.	

It appears that the blue unfossiliferous marls No. 1, are now known to contain a few small fresh-water and terrestrial species.

The following table will give some of the other Continental terms for the different parts of the British series :—

British.	D'Orbigny.	Feet.	Other Authors.
Wanting.	Danien .	50.	Craie pisolitique. Maestricht and Faxoe beds.
Chalk with and without flints.	Sénonien .	980.	Craie blanche, Kreide, Scaglia, Obere and Untere Kreide, and Planer Kalk, Zone de Rudistes, Calcaire à Hippurites.
Chalk Marl.	Turonien .	650.	Craie tufau, ou chloritée.
Upper Greensand.	Cenomanien	1600.	Glauconie crayeuse, Quadersandstein, Tourtia, Oberer Karpathensandstein, Système nervien.
Gault.	Albien .	150.	Système Aachénien, argiles tégulines (in part).
Speeton Clay.	Aptien .	650.	Argile à plicatules, Argiles tégulines (in part.)
Lower Greensand and Wealden beds.	Neocomien	8000.	Calcaire à spatangues, Argile ostréene, Calcaire à Dicérates, Hils conglomerat, and Hilsthon, Marne de Hauterive, Terrain Jura-Cretacée, Biancone.

M. Alcide D'Orbigny says that the Neocomien beds between Marseilles and Cassis, and between Clujes and Beausset, dip at 23° for a distance of 8 kilometres, or nearly five miles, which gives, he says, a thickness of 2500 metres (8200 Eng. feet).

The thickness of his Aptien beds he gets at Bedoule in the Basses Alpes ; and those of his Cenomanien and Turonien he takes from the measurements of M. Ed. de Verneuil (a most trustworthy authority) made in the provinces of Biscay and Santander in Spain.—(*Cours Elementaire de Palæontologie*, A. D'Orbigny, tom. second.)

North America.—Sir C. Lyell describes in his Manual sandy and argillaceous beds as existing in New Jersey, and containing fossils of

the same species as those of the Chalk of Europe. They extend through North Carolina and Georgia round the southern termination of the Appalachian chain into Alabama and Mississippi.

In Dr. Hector's recently published paper (Q. J. G. S., vol. xvii.), a great series of sandstones and clays and shales is described as occupying all the central part of British North America east of the Rocky Mountains. These beds are full of fossils belonging to the genera *Exogyra*, *Inoceramus*, *Baculites*, *Scaphites*, and other Cretaceous forms. They likewise contain fossil plants and wood, and beds of good coal, some of which are six feet thick, and are said by Dr. Percy, who examined specimens in his laboratory, to look very like coal from the Coal-measures.—(*Percy's Metallurgy*, p. 89.)

Messrs. Meek and Hayden have described the extension of these beds southwards into the American States.

South America.—Mr. Darwin describes in the Andes of the neighbourhood of Coquimbo, great beds of brown argillaceous limestone, porphyritic conglomerates, and masses of red sandstone with gypseous rocks, not less than 6000 feet thick, as containing in some parts fossils such as Hippurites and Baculites, and others clearly Cretaceous, together with Spiriferæ like Sp. Walcottii and other fossils more like Oolitic than Cretaceous species.—(*South America*, Darwin, p. 212, etc.) He says in his summary, *ib.*, p. 238, that strata characterised by Cretaceous or Oolitico-cretaceous fossils, having in many places a thickness of 7000 or 8000 feet, may be traced from Columbia north of the Equator to Tierra del Fuego. They consist of "black calcareous shaly rocks, of red and white siliceous sandstones, coarse conglomerates, limestones, tuffs, dark mudstones, and those singular fine-grained rocks which I have called pseudo-honestones, vast beds of gypsum and many other jaspery and scarcely describable varieties, which vary and replace each other in short horizontal distances to an extent I believe unequalled even in any tertiary basin." "In Tierra del Fuego, at about this same period, a wide district of clayslate was deposited,* which, in its mineralogical characters and external features, might be compared to the Silurian regions of North Wales."—(*Ib.*, p. 239.)

India.—Deposits at Pondicherry, Verdachellum, and Trichonopoly, examined by C. J. Kaye and the Rev. W. H. Egerton, were shewn by Professor E. Forbes's examination of the fossils to belong to the Cretaceous Period, the Pondicherry beds to the lower part of it, and those of Trichonopoly and Verdachellum probably to the Gault and Upper Greensand.—(*Q. J. Geol. Soc.*, vol. i., p. 79.)

* Mr. Darwin, of course, means that clay was deposited which was afterwards metamorphosed into slate.

Life of the Period.

If, as before, we fix our attention chiefly on the facts to be observed within the British area, we shall find no lack of interesting subjects for thought in contemplating the progress of life during this period.

The old dirt beds and fossil forests of the Purbeck rocks shew to us the actual surfaces of the land which existed in parts of this area at the close of the Oolitic Period. The fresh-water deposits with which these are associated, and the thick but irregular and partially deposited Wealden beds, disclose to us the existence of a large tract of land on which alone fresh water could have been gathered to form a delta 200 miles across. It is possible that several rivers may have united to form this delta, as is the case now in New Guinea, where an island, the main mass of which is not more than 600 miles across, has yet a part of its coast, 120 miles long, occupied by a continuous delta extending for an unknown distance into the interior, traversed by numerous channels of fresh water, with a large shallow flat spreading 30 or 40 miles out to sea all along it.—(See *Voyage of H. M. S. Fly.*)

The tenants of this land were some Marsupial and other Mammals, none of which were of large size, so far as we can judge from those remains of them that have come down to us. There were also huge reptiles, some carnivorous, like the Megalosaurus, others herbivorous, as the Hylæosaurus and Iguanodon. Other more crocodilian reptiles flourished in the seas or fresh waters of the Wealden times.

Fresh-water shells and drift wood are found in these deposits, as might be expected from their origin.

The land must have endured for many ages to form local deposits, which may be likened in thickness and extent to the deltas of the Ganges or the Nile ; but there came at length a time when it sank again beneath the sea, and these fresh-water deposits were finally buried under a thickness of some 2000 feet of marine accumulations.

In these seas lived and flourished the usual abundance of life.

Of minute Foraminiferæ there is an enormous abundance in the Chalk, parts of which seem to be almost entirely composed of the shells of Rotalia, Spirulina, and Textularia.—(*Green's Manual of Protozoa.*)

Sponges are abundant in all the Upper Cretaceous beds, except the Gault, and Actinozoa and Polyzoa in all.

It is remarkable that among the Corals the whole order Rugosa disappears at the close of the Palæozoic epoch, and would have been supposed to be entirely extinct then, if it were not for the appearance of one little species belonging to it in the Lower Greensand, namely,

the Holocystis elegans. The Cretaceous Corals belong chiefly to the Aporosa and Perforata; the family of the Madreporidæn ow first making its appearance, and probably also those of the Pennatulidæ and Gorgonidæ.—(*Greene's Cœlenterata.*)

Brachiopods are numerous in some beds, but their relative importance has now much decreased.

Conchifera are especially abundant in the Lower Greensand, and are not by any means rare in any member of the series. The peculiar genus Inoceramus, closely allied to the existing genus Perna, is very abundant in the Upper Cretaceous series, and the still more strange family of the Rudistæ, containing the genera Hippurites, Radiolites, Caprotina, and Caprina, which, in the south of Europe and other parts of the world, are characteristic of that division. In these shells one valve is always larger than the other, and in some is so rough and coarse as to have been taken for a Coral, while the other valve is small and flat, and looks like a limpet sticking on the larger one. The whole family is confined to the Upper Cretaceous group.—(See *Woodward's Manual of the Mollusca.*) It is singular that in Britain the bivalve shells belonging to the so-called Dimyarian sub-division are much rarer than the Monomyarian Conchifers.

Gasteropods are pretty equally distributed throughout all the sub-divisions of the Cretaceous period in Britain, except in the upper part of the Chalk. In the Irish Chalk, however, they seem to be numerous.

The Cephalopoda of the Cretaceous Period are very remarkable, and as after the close of this period they cease to play the important part which they did during the latter part of the Palæozoic, and through all the Mesozoic epoch, we may take this opportunity of casting a glance over their history.

The Cephalopods are divided into two orders, Dibranchiata and Tetrabranchiata. To the former belong the Cuttlefish or Sepia, the Squids or Calamaries, and the Argonauts of the present day, and many extinct genera, among which the Belemnites are most conspicuous. Of the Tetrabranchiata the only living representative is the Nautilus pompilius, but the extinct species and genera are very numerous. All their shells are divided into many chambers, and they may be classed into two series, according to the form of the septa or divisions between those chambers, and the position of the siphuncle or tube which traverses them. These two series are the Nautilidæ and the Ammonitidæ.

In the Nautilidæ the septa are simple, like plain saucers in form, and the siphuncle is internal, and generally at or near the centre of the shell. In the Ammonitidæ the septa are notched, or dentated, or corrugated and foliated, like saucers with waved or frilled margins, and

the siphuncle is at the dorsal edge of the shell, sometimes forming a prominent ridge along it.

In the Nautilidæ, when the conical chambered shell is straight it is called Orthoceras; when it is closely coiled, so that the whorls touch, it is a Nautilus. If the whorls of the largest part of the shell do not touch, it is a Lituite. There are also some other rarer modifications. The Lituites appeared in the Lower Silurian Period, and became extinct at the close of the Upper Silurian Period. The Orthoceras appeared in the Lower Silurian Period; underwent during the Upper Silurian Period several strange modifications of external form, by bulging of the sides, and contraction of the mouth (Gomphoceras, etc.); became of such large size during the Carboniferous Period as to have shells as big as a man's leg, and then died out with the close of the Palæozoic epoch.

The simple and elegantly formed Nautilus was in existence before the Carboniferous Period, had several species during that time, and has been represented by one or two species, differing in no more essential character than in external form, in every subsequent period down to our own day.

The Ammonitidæ appear to have commenced with the intermediate genus Clymenia, which diverged from the Nautilidæ in having its septa greatly waved and notched, and its siphuncle on the internal margin of the shell. These shells appeared at or a little before the Carboniferous Period, during which the Goniatite, which had its septa bent at the edges into sharp dog-toothed indentations, became very abundant. These became extinct with the close of the Palæozoic epoch.*

In the Mesozoic epoch we first of all find in the Muschelkalk the genus Ceratites, in which the edges of the septa are waved into round undulations, the backward curves being sharply notched with several small crenulations. The Ceratite thus leads us from the Goniatite to the Ammonite,† in which the edges of the septa are not merely waved and corrugated, but are often in addition so minutely crimped or zig-zagged as to resemble the edge of a parsley leaf, while the shell varies indefinitely in external size, form, and ornamentation, so that not less than 600 species have been described. Palæontologists have divided these numerous species into 20 groups, as in the following table:—

* The extinction of the Orthoceras and Goniatite at this time is true for the British area. In the Hallstadt and St. Cassian beds it will be recollected that they are found with fossils of a later date.

† The Ammonites appear to have had double opercula, small triangular bodies having been found associated with them, sometimes in pairs, which are supposed to be those appendages. They have been called Trigonellites and Aptychus.—(*See Mantell's Medals*, chapter xii.)

NAME OF GROUP.	EXEMPLAR SPECIES.	ROCKS IN WHICH THEY OCCUR.
1. Arietes.	A. bisulcatus.	Lower Lias.
2. Falciferi.	A. serpentinus.	Lias to Oxford Oolite.
3. Cristati.	A. inflatus.	Cretaceous.
4. Amalthei.	A. cordatus.	Lias to Oxford Oolite.
5. Pulchelli.	A. crenatus.	Oxford Clay to Cretaceous.
6. Clypeiformi.	A. Requienianus.	Oolitic and Cretaceous.
7. Dentati.	A. denarius and Jason.	Oolitic and Cretaceous.
8. Gemmati.	A. aon.	Triassic.
9. Flexuosi.	A. radiatus.	Lower Cretaceous.
10. Compressi.	A. Beaumontianus.	Cretaceous.
11. Armati.	A. perarmatus.	Middle and Upper Oolitic.
12. Angulicostati.	A. Milletianus.	Cretaceous.
13. Capricorni.	A. planicosta.	Liassic.
14. Heterophylli.	A. Guettardi and heterophyllus.	Liassic to Cretaceous.
15. Ligati.	A. Mayorianus.	Cretaceous.
16. Planulati.	A. biplex.	Upper Lias to Portland Oolite.
17. Coronarii.	A. Humphresianus.	Upper Lias and Lower Oolite.
18. Macrocephali.	A. microstoma.	Middle Lias to Lower Cretaceous.
19. Globosi.	A. globus.	Triassic.
20. Fimbriati.	A. subfimbriatus.	Triassic to Cretaceous.

In the Cretaceous period the Ammonitidæ varied not only in the size, shape, and ornamentation of the involute shell, but in the disposition of the volutions themselves. In the genus Crioceras the whorls of the shell no longer touch each other, the coil being an open one as in the Lituite among the Nautilidæ. In the genus Scaphites the shell when young was like an Ammonite, but at a certain period of growth the shell was projected straight out, and then curled in the reverse way, so as somewhat to resemble a boat in form (see Foss. gr. 38, p. 615). In Ancyloceras,* the general form is that of a Scaphite, but the young part is open like Crioceras. In Anisoceras the form is that of Ancyloceras, except that the young part rises from the plane of the shell into an open spiral form. In Heteroceras this young spiral part of the shell is close, the whorls of the shell touching in that part. In Turrilites this close spiral form is carried out through the whole shell, so that the form of the shell is a tall spiral like a Turritella, Cerithium, or Terebra. Helicoceras* again is an open Turrilite, in which the whorls do not touch. Then we have Hamites, in which there is only one curve in the shell, which is bent into the form of a hook, Ptychoceras, which is a Hamite with the two arms of the hook squeezed together so as to touch. In Toxoceras,* on the other hand, the shell is merely bent like a bow; and, lastly, comes Baculites, in which the shell is straight like a

* These forms commenced during the Oolitic period.

walking stick, so that the Baculite is to the Ammonitidæ what the Orthoceras is to the Nautilidæ.—(See *Mantell's Medals*, chapter xii.)

It is curious that all these strange modifications in the involution of these complex shells should appear just before the whole family became utterly extinct and left no farther representatives in the world; while the plain and simple Nautilus, commencing in earlier times, has never yet died out, but has never had the multitude of species into which the Ammonite has varied.

Among the Echinodermata it appears that the Crinoidea or Sea Lilies were scarcely more abundant in the Cretaceous Period than they are now—the Marsupite, a floating form, being of the most frequent occurrence. The Echinidea, or Sea Urchins, however, were wonderfully numerous during the latter part of the period, the true Chalk containing numerous genera, many of them having many species, and some of these being abundant in individuals. Some of the genera existed during the Oolitic Period, having different species in different parts of it, and other species during the Cretaceous time. Other genera, however, have only been found in the Cretaceous rocks, while a few have been represented by different species in later times; one or two genera being continued by successive specific forms down to our own day.

Among the Annelida a few Serpula have been preserved.

Of the Crustacea we find some pedunculated Barnacles (see *Mantell's Medals*, fig. 167), many Cypridea, and a few of the Podophthalmia, the order to which our own crabs and lobsters belong.

Of the Insects, a few remains have been found in the Wealden beds, but none in any other part of the Cretaceous series, though, as Mr. Brodie has shewn them to have been so abundant in even the earliest part of the Oolitic Period, we cannot attribute the absence of their remains in the Cretaceous rocks to anything else than the want of the requisite conditions for their proper preservation.

When we come to the Vertebrata, we find in parts of the true Chalk abundant remains of Fishes, most of which more nearly resemble the Fish of the present day than do the Fish found in earlier formations. The whole order Teleostei, indeed, which includes the Cod, the Salmon, the Perch, and all the most ordinary existing fish, came first into existence during the Cretaceous Period. Remains of other orders of fish, however, especially teeth of Squalidæ or Sharks, are by no means wanting in Cretaceous rocks.—(See *Mantell's Medals*, fig. 193.)

Reptiles certainly abounded during the Cretaceous Period. The great land carnivorous reptile (Megalosaurus) survived from the period of the Bath Oolites, and inhabited the land the washing of which formed the Wealden beds. It was contemporaneous, then, with the equally large but herbivorous Hylæosaurus and Iguanodon, the three genera making the natural order of the Deniosauria, according to Owen.

Besides these, there were many other Reptiles, both Saurian and Chelonian, during the Wealden Period, and the marine Ichthyosaurus and Plesiosaurus were represented even in the times when the Chalk itself was in course of deposition, though no species similar to them lived at a later period. The Mososaurus was more like a lizard than those already named, though still marine, and so large as to have a cranium five feet in length. The forms seem to have been peculiar to the latter part of the Cretaceous Period. The Pterodactyles, or winged reptiles, seem during the middle part of the Cretaceous period to have attained their maximum in size, as well as perhaps in number, since those of the Lias and Oolites were not much larger than ravens or cormorants, while those from the Upper Greensand of Cambridge had neck vertebræ two inches long, and a probable expanse of wings equal to twenty feet.—(*Owen's Palæontology*, p. 247.)

Since Birds certainly existed during earlier periods than the Cretaceous, as is shewn by the tracks described by Hitchcock in North America, they can hardly have been non-existent during any subsequent time. The remains of one bird indeed have been actually procured by Mr. Barrett from the Cambridge Greensand, and indicate, according to Professor Owen, a bird about the size of a woodcock.

Mammals in like manner must have existed ever since the period of the Stonesfield slate, but no Mammalian remains have been found in any deposits belonging to the Mesozoic epoch above the Purbeck beds, not even in the Wealden beds, so abounding in terrestrial fragments.

The following is an approximately accurate summary of the genera which, so far as we know, first came into existence during the Cretaceous Period; those marked by an asterisk not having endured beyond its close:—

Plants, * Abietites. * Clathraria, Dracæna.

Foraminifera, Gaudryina, Globigerina, Guttulina, Lingulina, Lituola, Orbitolina, Orbitolites ? * Planulina, * Pyrulina, Quinqueloculina, Rosalina, Truncatulina, Verneuilina.

Spongidæ, * Achilleum, * Brachiolites, * Cephalites, Chenedopora, * Choanites, * Cæloptychium, * Guettardia, Hippalimus, * Jerea, * Paramoudra, * Plocoscyphia, * Polypothecia, * Siphonia, Udotea, * Ventriculites.

Actinozoa, * Acanthocænia, * Actinacis, * Anabacia, * Aspidiscus, * Baryhelia, Barysmilia, Bathycyathus, * Brachycyathus, Brachyphyllia, Caryophyllia, Centrocænia, Cladocora, Corallium, * Cyclocyathus, Cyclolithus, Cycloseris, Cyphastræa, * Dactylosmilia, * Dimorphastræa, Diploctenium, Diploria, * Elasmocænia, * Genabacia, Goniastræa, * Heterocænia, * Holocænia, * Holocystis, Hydnophora, * Hymenophyllia, Isis, * Koninckia, * Leptophyllia,

Leptoria, Lophosmilia, * Mæandastræa, * Micrabacia, Mycetophyllia, * Parasmilia, Pavonaria, * Pentacœnia, * Peplosmilia, Phyllocœnia, * Placocœnia, * Placosmilia, * Pleurocora, * Polytremacis, Rhizangia, * Smilotrochus, * Stellornisa, Stephanophyllia, Stylocœnia, * Stylocyathus, * Synhelia.

Polyzoa, * Actinopora, * Atagma, * Ceriocava, * Clypeina, * Desmeopora, * Domopora, * Entalophora, Eschara, Flustra, * Holostoma, * Homæosolen, Lunulites, * Multicrescis, * Proboscina, * Radiopora, * Reptocea. * Reptomulticava, * Reptotubigera, * Siphoniotyphlus, * Zonopora.

Brachiopoda, Argiope, * Magas, Terebratulina, * Terebrirostra, * Trigonosemus.

Conchifera, Amphidesma, * Caprina, * Caprinella, * Caprotina, Chama, Crassatella, Cryptodon, * Diceras (Requienia), Gastrochæna, * Hippurites, Neæra ? Pachymya, Petricola, * Radiolites, Solecurtus, Spondylus, Tellina,[1] Teredo,[1] Thetis, Venus.[1]

Gasteropoda, Aporrhais, * Avellana, Cassidaria ? Dolium ? * Hipponyx, Nassa, Phorus, Pyrula, Rostellaria, Scalaria, Tylostoma, Voluta.

Heteropoda, * Bellerophina.

Cephalopoda, * Baculites, * Belemnitella, * Crioceras, * Hamites, * Helicoceras, * Ptychoceras, * Scaphites, * Turrilites.[2]

Echinodermata, * Ananchytes, * Arthraster, Bourgueticrinus, * Cardiaster, * Caratomus, * Catopygus, * Cyphosoma, * Discoidea, * Galerites. Goniaster (sub-gen. Astrogonium, * Goniodiscus, * Stellaster), Hemiaster, * Hemipneustes (or Toxaster), * Marsupites, * Micraster, * Oreaster, * Pyrina, * Salenia.

Cirripedia, Loricula, Scalpellum, Verruca.

Crustacea, Cythereis, Cytherella, Cythereidea, * Enoploclyttia, Grapsus ? Mesostylus, * Meyeria, * Notopocorystes, Palinurus, Platypodia.

Fish, * Acrognathus, * Acrotemnus, * Aulodus, * Aulolepis, * Berycopsis, * Beryx, * Calamopleurus, Cestracion, * Cladocyclus, Cœlorhynchus, * Corax, * Decretis, Edaphodon, * Enchodus, * Homonotus, Hypsodon, Lamna, * Lophiostomus, * Macropoma, Notidanus, Orthagoriscus, * Osmeroides, Otodus, * Oxyrhina, * Pachyrizodus, * Phacodus, * Plethodus, * Pomognathus, * Prionolepis, * Ptychodus, * Saurocephalus, * Saurodon, * Scylliodus, * Stenostoma, Tetrapterus, * Tomognathus.

Reptiles, * Coniosaurus, * Dolichosaurus, * Hylæosaurus, * Iguanodon, * Leiodon, * Mosasaurus, Platemys, * Pœcilopleuron, * Pelorosaurus, * Polyptychodon, * Protemys, * Raphiosaurus, * Regnosaurus, * Suchosaurus.

[1] Unless the shells so called in older rocks be rightly named.
[2] Unless one reported from the Lias be truly named.

At the close of the Cretaceous period, the following generic forms, dating their origin from still earlier times, became finally extinct :—

Plants, Alethopteris, C ; Chondrites,* S ; Confervites, P ; Cycadeoidea, O ; Endogenites, C ; Lonchopteris, O ; Sphenopteris, O ; Thuytes, O ; Zamiostrobus, O.

Spongidæ, Cnemidium, S ; Coscinopora, D ; Manon, O ; Scyphia, D ; Verticlites, S ?

Foraminifera, Bulimina, O ; Flabellina, O ; Frondicularia, O ; Sagrina, O ; Vaginulina, O.

Actinozoa, Adelastræa, O ; Calamophyllia, O ; Cladophyllia, T ; Cyathopora, O ; Enallohælia, O ; Haplophyllia, O ; Isastræa, T ; Pachygyra, O ; Pleurocænia, O ; Rhabdophyllia, T ; Rhipidogyra, O ; Stylina, O ; Stylosmilia, O.

Polyzoa, Alecto, O ; Ceriopora, S ; Pustulopora, C ; Vincularia, C.

Brachiopoda, There are no generic forms found fossil in the Chalk that have not some species living even at the present day, except those marked with an asterisk in the preceding list, and these are in reality sub-genera.

Rudistes, The whole family is confined to the Cretaceous period, none being known of either earlier or later date.

Conchifera, Exogyra, O ; Gervillia, C ? or O ; Gryphæa, O ; Inoceramus, C ? or O ; Myacites, S ; Opis, T ; Sphæra, T.

Gasteropoda, Nerinæa, O ; Pleurotomaria, S.

Pteropoda, No extinct genus survived into the Cretaceous period.

Cephalopoda, Ammonites, T ; Ancyloceras, O ; Belemnites, T ; Turrilites,† L ?

Echinodermata, Collyrites, O ; Echinobrissus, O ; Holectypus, O ; Pygaster, O ; Pygurus, O ; Rhabdocidaris, O.

Fish, Acrodus, T ; Æchmodus, O ; Asteracanthus, O ; Belonostomus, O ; Caturus, O ; Hybodus, T ; Ischyodus, O ; Lepidotus, O ; Microdon, U O ; Sphenonchus, O ; Strophodus, O.

Reptiles, Cetiosaurus, O ; Goniopholis, U O ; Ichthyosaurus, O ; Megalosaurus, O ; Plesiosaurus, O ; Pterodactylus, O ; Streptospondylus, O ; Tretosternon, O.

* These plants do not range higher than the Wealden and Lower Greensand ; this and the three following are not genera in the ordinary sense of the term, but merely provisional groups.

† Provided the Turrilites Valdani for the Lias be rightly determined.

THE TERTIARY OR CAINOZOIC EPOCH.

CHAPTER XXXV.

EOCENE PERIOD.

Preliminary Observations.—The nomenclature of the Tertiary periods proposed by Sir C. Lyell, and now all but universally adopted, is more systematic than that of the Primary or Secondary periods. It is based on the gradual increase of recent (*i.e.*, existing) species in the newer rocks. The earliest of the periods is termed Eocene, from the Greek words eos and kainos or cænos, signifying the dawn of the recent; the second, Meiocene, from meion, the minority; the third, Pleiocene, from pleion, the plurality of recent species; and the next, Pleistocene, which expresses the recentness of most of the species.

To these we may add the present period itself, which we may perhaps conveniently designate as the Recent or the Human Period, though it is now difficult to draw any line of separation between the Pleistocene and the Recent Period.

The adoption of this principle of classification was rendered more necessary in the case of the Tertiary than the preceding epochs, from the nature of the physical conditions of Western Europe, on the structure of which our classification is chiefly based.

In the Primary and Secondary epochs, the part now occupied by Western Europe seems to have generally contained more sea than land, and the rocks deposited are accordingly so widely spread as frequently to rest one upon the other. We can therefore often determine their order of superposition by their geognostic relations only, that is, by actually tracing each group of beds till we find it plunging under the superior group on the one side, or till the inferior group rises up to the surface from underneath it on the other. When, however, we come to examine the Tertiary rocks of the same area, we find that, either from

having been deposited in separate seas, or from subsequent denudation, or both combined, they now form detached patches, each patch ending before it comes in contact with the rest, so that their order of superposition can rarely be determined by simple inspection. To take a conspicuous instance at once—The Chalk of the south-east of England is continuous with that of France* and Belgium, and no mistake could possibly be made as to the relative position of the beds above and below it. The Oolites below the Chalk are even still more extensive, and can be traced both geognostically and palæontologically. The Tertiary beds above the Chalk, however, form isolated districts in the hollows of the Chalk, one being called the Hampshire basin, another the London, and a third the Paris basin; and if we wish to determine whether the beds of these three districts are of the same age, or one older than another, it is obvious that we can no longer employ the positive evidence of an inspection of their superposition. We must then have recourse either to the petrological evidence of their being made exactly of the same kinds of rock occurring in the same order, or to the palæontological evidence of their containing the same assemblages of fossils occurring in the same order; but if neither rocks nor fossils were precisely the same, then we must fall back on the general rule or principle just spoken of, and see which contained an assemblage of fossils having the greatest approximation to living forms, and this in the case of Tertiary rocks is most easily determined by the relative percentage of actually existing species.

The British Eocene Beds.

In the description of the range of the Chalk across England, it was pointed out that a nearly continuous escarpment extended from the Wolds of Yorkshire into Dorsetshire, and that the dip of the beds was from the escarpment towards the east, at a gentle angle. It follows that, as the top of the Chalk declines towards the east, and sinks beneath the level of the ground, it must become covered by some other formations.

In Yorkshire, Lincolnshire, and Norfolk, the escarpment of the Chalk runs almost parallel to the sea-coast; and in consequence of that, and its gentle dip, the formation has no room to acquire any depth before reaching the sea. From Suffolk, however, it strikes directly south-west, through the heart of the country to Dorset, while its general dip is towards the south-east. It becomes covered towards the south-east, therefore, by a very considerable thickness of beds of more recent formation, most of which belong to the Eocene Period.

There can be little doubt that some of the lowest of these Eocene

* That the shallow furrow of the Straits of Dover has been worn down a little way below the level of the sea into the body of the Chalk does not of course affect this assertion.

beds, if not the whole of them, once stretched horizontally across the whole south-east corner of England, from the coast of Suffolk to that of Dorsetshire. Since that time, however, the rocks below have been abruptly elevated along the two east and west lines, or axes, mentioned before, the one running from Salisbury Plain through the Weald of Kent, and the other along the south coast of Dorset and the southern part of the Isle of Wight.

The denudation consequent on the lifting of the rocks along these two bands has removed not only the Eocene beds, but in some parts the whole of the upper and a good part of the lower Cretaceous series. Where, however, the elevation was not so great, the Cretaceous rocks have been spared, as for instance on Salisbury Plain and the Chalk between it and the Weald; and here, in the country north-east and south-east of Alresford, little outlying patches of the Eocene beds have also been left unremoved on the top of the Chalk. (See Map Sheets 11 and 12 of the Geological Survey, or Professor Ramsay's Map of England and Wales).

It is, then, in consequence of this subsequent elevation and denudation that the Tertiary beds, which repose in a hollow of the Chalk around London, are separated from those lying in the hollow of the Chalk around Southampton.

The Chalk beds of the North Downs, running from Deal and Dover to Guildford and Basingstoke, dip to the north and plunge under the valley of the Thames, to a depth of many hundred feet, from which they rise very slowly and gradually out towards the north-west. Any one travelling, even by railway, from London southwards to Reigate, on the one hand, or in a north-westerly direction, to Tring, upon the other, will see the difference between the bold rise of the Chalk from beneath the London basin on the south, and its slow and gradual elevation on the north.

In the Hampshire basin the same features are still more marked, since the Chalk, with the superincumbent Eocene beds dip very gently southwards from Salisbury and Winchester to the Isle of Wight, where they are suddenly bent up into a position of absolute verticality.

The Eocene beds of England rest upon the upper surface of the Chalk in apparent conformity; that is, there is no apparent difference in the dip or strike of the two groups. There is, however, a real unconformity between them, inasmuch as the Chalk presents a worn and eroded surface for the base of the Eocene beds. (See *ante*, chapter on *Unconformability.*)

Owing to the character of the ground, there is no one place where a good continuous section of the Eocene beds is to be seen in the London basin.

In the Hampshire basin, however, especially on the south side of it,

in the Isle of Wight, where the beds are tilted up along with the Chalk, and exposed in the sea cliffs, excellent sections are to be seen. The following fig. 121, is a diagrammatic section of the beds as they are shewn along the western shore of the Isle of Wight. It is reduced from the one drawn by Mr. Bristow, and published in the *Memoirs Geol. Surv.* (*Tert. Fluv. Mar. formation of I. of Wight.* See also *Sheet* 47 *Hor. Sect.*, and *Sheet* 25 *Vert. Sect.*, by same author).

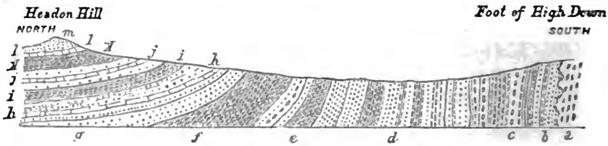


Fig. 121.

Length of section about 700 yards.

m. The high level gravel.
l. Bembridge beds.
k. Osborne beds.
j. Upper Headon beds.
i. Middle Headon beds.
h. Lower Headon beds.
g. Upper Bagshot beds.
f. Barton clay.
e. Bracklesham beds.
d. Lower Bagshot sands and clays.
c. The London clay.
b. The Plastic clay and sands.
a. The Chalk (with eroded surface), having many layers of flint.

NOTE.—In this figure the wood-engraver has unfortunately not copied the original drawing quite accurately, but has made the lines of the group *f* end against the base of the group *g*, as if the Upper Bagshot beds rested unconformably on the Barton clay. The lines of *f* should have been drawn parallel to its boundaries on each side.

In this section we have within the space of half a mile the whole of the British Eocene series, with the exception of the uppermost member, namely, the Hempstead beds, which are found on a hill four or five miles east of Headon Hill.

Including these, and tabulating the whole series, as it may be seen in both the London and Hampshire basins, we get the following list of consecutive groups; the thicknesses in which are taken, so far as regards the Upper and Middle Eocenes, from the *Survey Memoir* by Professor Forbes and Mr. Bristow, entitled *Tertiary fluvio-marine Formation of Isle of Wight;* those of the Lower Eocene are chiefly from Mr. Prestwich's papers on different parts of the London basin. They are either the maximum thickness anywhere observed, or the mean of the maxima at different places.

TYPICAL GROUPS OF ROCK.—London and Hampshire basins—

				Feet.	
UPPER EOCENE.	8. Hempstead series.	d. Corbula beds . .	15	170	
		c. Upper freshwater and estuary marls	40		
		b. Middle . . .	50		
		a. Lower . . .	65		
	7. Bembridge series.	d. Upper marls . .	90	115	
		c. Lower marls . .			
		b. Oyster bed . .			
		a. Limestone .	25		
MIDDLE OR PARIS EOCENES.	6. Osborne series.	b. St. Helen's sands .	50	70	
		a. Nettlestone grits .	20		
	5. Headon series.*	c. "Upper freshwater"	85	200	
		b. Middle marine .	50		
		a. "Lower freshwater"	65		
	4. Bagshot series.	d. Upper Bagshot .	200	1270	
		c. Barton clay .	300		
		b. Bracklesham beds .	110		
		a. Lower Bagshot .	660		
				——	1540
LOWER OR LONDON EOCENES.	3. London clay or Bognor series	. . . . . .			480
	2. Plastic clay	. . . . . .			160
	1. Thanet sands	. . . . . .			90
					2560

THE LOWER EOCENE GROUPS.

1. THANET SAND.—Light-coloured quartzose sand, mixed in the lower beds with much argillaceous matter, but never passing into actual clay ; containing occasionally dark green grains, like those mentioned before in the Greensands. It rests almost invariably on a stratum of chalk flints, from which the chalk seems to have been washed away without wearing or fracturing the flints, and these are of a bright olive colour externally, by which they may be recognised in other beds (tertiary or drift), to which they may have been subsequently carried. The Thanet sands are very constant in character from the Isle of Thanet throughout the London basin, but thin out to the westward, till a little north of Windsor they are only four feet thick, shortly beyond which the beds disappear entirely.—(Prestwich, *Geological Journal*, 1852, p. 235.)

They may be seen abundantly in the sand-pits and railway cuttings about Woolwich.—(See *Geological and Topographical Map of London and its Environs*, by R. W. Mylne, F.G.S.)

2. THE PLASTIC CLAY, or the Woolwich and Reading series of

* The total thickness of the fluvio-marine strata of the Isle of Wight, reckoning from the base of the Headon series, will be from 500 to 560 feet.

Prestwich. This group is more variable in character than that of the Thanet sands, and also more widely extended, becoming thicker from east to west, or in the opposite direction to the Thanet sands.

On the east, near Herne Bay, we have in it—

	Feet.
c. Argillaceous greensand	12
b. Dark gray argillaceous sand with nodules of iron pyrites	7
a. Light ash green and yellow sands	9
	28

At Black Heath it consists of—

	Feet.
Pebble beds	12
Brownish sand	2
Comminuted shells in light coloured clay with pebbles	6
Light green sandy clays	7
Light green sands with pebbles	6
	33

Near Reading the beds are—

	Feet.
e. Mottled red and light bluish gray clay	20
d. Laminated yellow sands	2
c. Light gray and greenish sandy clay	4
b. Fine yellow sand	8
a. Greensand with Ostræa Bellovacina	2
	36

But these beds are more than fifty feet thick in other parts of the district.

At New Haven, an outlier of the Hampshire district—

	Feet.
i. Gray clay and dark yellow sand	12
h. Round flint pebbles in gray clay and yellow sand	1
g. Laminated gray clay with seams of yellow sand	8
f. Concreted oyster rock (O. Bellovacina)	2
e. Comminuted shells in yellow sand and gray clay	6
d. Yellow, brown, and red sand in layers	5
c. Dark gray clays with ironstone	20
b. White, ochreous, and green sand	25
a. Green and ferruginous-coated flints in sand	2
	81

In Alum Bay, Isle of Wight, these beds are from 90 to 140 feet thick, consisting of bright-coloured tenacious mottled clays, the prevailing colour being blood-red, but having mixtures of light-bluish gray and yellow, light and dark slate colour, lavender, puce, yellow, and brown—almost free from any admixture of sand.—(Prestwich, *G. J.*, 1854, vol. x. p. 75.)

The Druid Sandstones, Gray Weathers, Sarsenstones, and Puddingstones, scattered in loose blocks over many of the Chalk downs around the London basin, are believed by Mr. Prestwich to be consolidated portions of the sands and gravels of the Plastic clay series.

3. THE LONDON CLAY.—In the London basin this consists of—

b. Dark gray and brown clay, with layers of septaria or cement-stones, varying from 200 feet on the west to 480 on the east about Sheppey Island.

a. Basement bed, yellow, green, and ferruginous sands, and occasionally clays with layers of rounded flint pebbles, having a total thickness of about five feet, and resting on the slightly eroded surface of the beds below.

In the Hampshire basin we have—

b. Dark blue clays and sands, containing nodules of argillaceous ironstone with bands of gray clayey sands and dark-greenish sands, sometimes compacted into hard stone called Bognor rock, having a total thickness varying from 193 to 363 feet.

a. Basement bed of sand and clay, with a conglomerate of round flint pebbles and partly rounded fragments of chalk and of the mottled clays below, 4 to 5 feet.

Characteristic Fossils of the Lower Eocenes.—Each of the groups now described has in reality a characteristic assemblage of fossils, many of which are peculiar to the group, while others are more abundant in it than elsewhere. The groups are also linked together by fossils which range from one group into that above, or into still higher beds. In the first edition of this work, lists of the characteristic fossils of each group were given, and also those which were common to two or more groups. Time and space, however, alike forbid the revision of these lists, and compel me to substitute for them the following list of characteristic fossils of the Lower Eocene beds taken together; but prefixing the numbers 1, 2, or 3, to such species as may be peculiar to one or more of the three lower Eocene groups—

Plants.

3. Hightia elegans	Bow. Foss. Fr.*
3. Leguminosites, several species . .	*Ibid.*

* Bowerbank's Fossil Fruits of the London Clay.

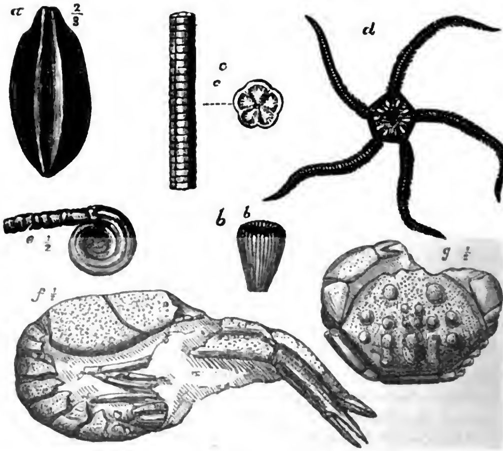
3.	Nipadites umbonatus	Foss. gr. 40, *a*.
3.	Wetherellia variabilis	Bow. Foss. Fr.

Foraminifera.

1 and 3.	Cristellaria Wetherellii . .	Q. J. G. S., viii.
3.	Dentalina acuta	D'Orbigny.

Actinozoa.

3.	Dasmia Sowerbyi	Br. Foss. Cor.
3.	Paracyathus caryophyllus . .	Foss. gr. 40, *b*.



Fossil Group No. 40.
Lower Eocene Fossils.

a. Nipadites umbonatus.
b. Paracyathus caryophyllus.
c. Pentacrinus sub-basaltiformis.
d. Ophiura Wetherellii.
e. Vermicularia Bognoriensis.
f. Hoploparia Bellii.
g. Zanthopsis tuberculata.

Polyzoa.

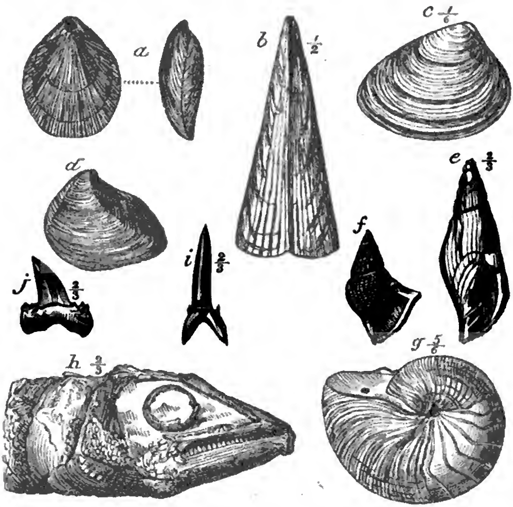
3.	Eschara Brongniarti	Dix. Foss. Suss.
3.	Flustra crassa.	

Brachiopoda.

3.	Lingula tenuis	Sow. M. C., 19.
3.	Terebratulina striatula . . .	Foss. gr. 41, *a*.

Conchifera.

3. Cryptodon angulatum	Foss. gr. 41, *d.*
2 and 3. Cyprina planata . . .	Sow. M. C., 619.
2. Cyrena cuneiformis	Foss. gr. 41, *c.*
3. Nucula Bowerbankii . . .	Geol. Tr., vol. v.
3. Ostræa Bellovacina	Sow. M. C., 388.



Fossil Group No. 41.

Lower Eocene Fossils.

a. Terebratulina striatula.
b. Pinna affinis.
c. Cyrena cuneiformis.
d. Cryptodon angulatum.
e. Voluta Wetherellii.
f. Aporhais Sowerbii.
g. Nautilus imperialis.
h. Cœlopoma Colei.
i. Lamna elegans.
j. Otodus obliquus.

2. Pholadomya margaritacea	Sow. M. C., 297.
3. Pinna affinis	Foss. gr. 41, *b.*
2. Syndosmya splendens	Tab. View.
2 and 3. Teredo antenautæ	Sow. M. C., 102.

Gasteropoda.

3. Aporrhais Sowerbii	Foss. gr. 41, *f.*
3. Cassidaria Smithii	Sow. M. C., 578.
2. Cerithium funatum	*Ibid.*, 147.
3. Cypræa oviformis	*Ibid.*, 4.
2. Melania inquinata	Ly. Man., fig. 234.
1. Trophon subnodosum	Q. J. G. S., viii.
3. Voluta Wetherellii	Foss. gr. 41, *e.*

Cephalopoda.

3. Belosepia sepioidea	Ly. Man., fig. 226.
3. Nautilus imperialis	Foss. gr. 41, *g.*

Echinodermata.

3. Astropecten crispatus	M. G. S., Dec. 1.
3. Goniaster Stokesii	*Ibid.*
3. Ophiura Wetherelli	Foss. gr. 40, *d.*
3. Pentacrinus sub-basaltiformis	Foss. gr. 40, *c.*

Annelida.

3. Vermicularia Bognoriensis	Foss. gr. 40, *e.*

Crustacea.

3. Hoploparia Bellii	Foss. gr. 40, *f.*
3. Zanthopsis tuberculata	Foss. gr. 40, *g.*

Fish.

3. Cœlopoma Colei	Foss. gr. 41, *h.*
3. Lamna elegans	Foss. gr. 41, *i.*
3. Otodus obliquus	Foss. gr. 41, *j.*

Reptiles.

3. Chelone breviceps	Owen, Foss. Rep.
3. Crocodilus champsoides	*Ibid.*
3. Palæophis toliapicus	*Ibid.*

Birds.

3. Halcyornis toliapicus	Owen, Foss. Mam.
3. Lithornis Vulturensis	*Ibid.*

Mammals.

3. Coryphodon Eocænus	Owen, Foss. Mam.
3. Didelphys Colchesteri	*Ibid.*
3. Hyracotherium leporinum	Geol. Tr., vol. vi.
3. Macacus Eocænus	Owen, Foss. Mam.
3. Pliolophus vulpiceps	——Palæontology.

The Middle Eocene Groups.

4. The Bagshot Series takes its name from Bagshot Heath, but is best seen in the Isle of Wight. It consists of four groups, namely :—

4 *a*. The Lower Bagshot beds, composed of alternations of sand and clay; the sands generally pale yellow or gray, but sometimes dark and ferruginous, at others fawn-coloured or rose-coloured; the clays are white pipe-clay, or gray or chocolate-coloured clay. Thickness, 660 feet.

4 *b*. The Bracklesham beds, so called from Bracklesham in Sussex, dark chocolate-coloured marls and carbonaceous clays below, over which are whitish marly clay and white sands capped by a band of conglomerate of flint pebbles. Thickness, 110 feet.

4 *c*. The Barton beds, greenish-gray sandy clay below, passing up into bluish-green and brown clay, interstratified occasionally with beds of sand and loam. Thickness, 300 feet. This was formerly supposed to be the London clay.

4 *d*. Upper Bagshot beds, yellow and white sands with ferruginous stains. Occasionally 120 feet.

(*Mr. Bristow's section in Mems. Geol. Survey*, 1856. *Forbes' Isle of Wight Mem.*)

This arrangement is different from that given by Mr. Prestwich in his papers in the Geological Journal. It appears that No. 16 of Mr. Bristow's section, p. 157, is the same as No. 24 of Mr. Prestwich's in Geological Journal, vol. ii. p. 258. All below that, Mr. Bristow calls Lower Bagshot, while Mr. Prestwich includes many of the sands below in his Bracklesham series.—(*Geological Journal*, vol. xiii. p. 99.)

5. The Headon Series.—All the Eocene beds described in the preceding pages, except part of the Plastic Clay series, are of marine origin. With the commencement of the Headon series, however, we meet with indications of fresh water having prevailed over what is now the Hampshire area, as well as at the corresponding period of the Paris tertiaries. In the London area no beds higher than the Bagshots are known.

5 *a*. The Lower Headon beds consist of 31 feet of clays and marls in Whitecliff Bay, while at Headon Hill and Colwell Bay they contain thick limestones, and are from 60 to 80 feet thick, and they are still more varied at Hordwell on the opposite coast. They are the "Lower Freshwater formation" of Webster.

5 *b*. The Middle Headon beds consist principally of sands, shewing at Headon Hill brackish water fossils, but containing beds of

oysters; while at Colwell Bay and Hordwell, and still more strongly at Whitecliff Bay, the beds have a purely marine character. Webster called them the "Upper Marine formation." At Colwell Bay they are only 23 feet thick, but at Whitecliff Bay they swell out to 100 feet.

5 *c*. The Upper Headon beds contain the strongest limestones of Headon Hill, where they are 85 feet thick, thinning out rapidly towards the north. They are represented by a few very thin and inconspicuous sandy concretionary bands, with a total thickness of only 44 feet in Whitecliff Bay. The uppermost beds of the group are marls. Webster gave the name of "Upper Freshwater formation" to this group.

6. Osborne Series.—This series varies from 50 feet in Headon Hill to 80 feet at Whitecliff Bay. It is divisible into two groups.

6 *a*. The Nettlestone grits consist of hard rag and shelly sandstone below, capped by marl and bright yellow limestone. The whole about 20 feet in thickness in some places, but in others thinning out and disappearing, or becoming a mere loose sand.

6 *b*. The St. Helen's sands, or uppermost part of the Osborne series, consist of an alteration of white, and green, and yellow sands, with blue, white, and yellowish clays and marls, having a total thickness of about 50 feet.

Characteristic Fossils of the Middle Eocene Groups.

Some of the beds just described contain in many places an enormous abundance of fossils, often in the highest state of preservation. Each group and each sub-group has fossils peculiar to itself as well as others common to it, and one or more other groups. The Barton Clays on the coast of Dorsetshire, and the Bracklesham beds of Sussex, are literally crowded with beautiful shells, of which a magnificent series may now be seen in the cases of the Museum of Practical Geology in Jermyn Street.

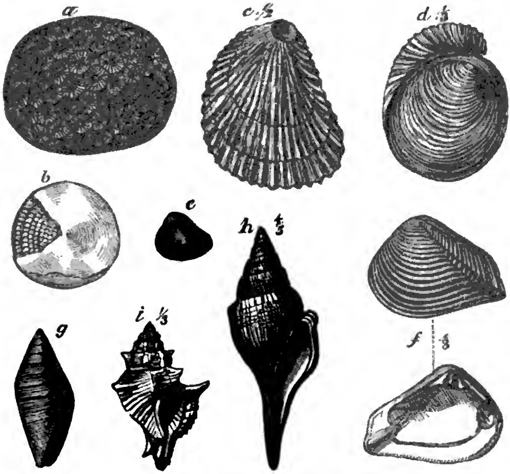
The following list contains a very meagre and imperfect selection from the completer lists of Middle Eocene fossils; the numbers prefixed referring as before to the groups.

Plants.

6. Chara Lyellii . . . . Geol. Tr., vol. ii.
4*b*. Comptonia dryandrifolia . . Brongniart.
4*a*. Leaves of trees beautifully preserved in pipe clay.

Foraminifera.

4*b*.	Nummulites lævigatus	Foss. gr. 42, *b*.
4*b*.	Quinqueloculina Hauerina	Dix. Foss. Suss.
4*b*.	Rotalina obscura	*Ibid.*
4*c*.	Triloculina coranguinum	*Ibid.*



Fossil Group 42.
Middle Eocene Fossils.

a. Litharea Websteri.
b. Nummulites lævigatus.
c. Ostræa flabellula.
d. Chama squamosa.
e. Corbula pisum.
f. Crassatella sulcata.
g. Conus dormitor.
h. Fusus longævus.
i. Murex asper.

Actinozoa.

4*b*.	Litharea Websteri	Foss. gr. 42, *a*.
4*c*.	Turbinolia Bowerbankii	Br. Foss. Cor.

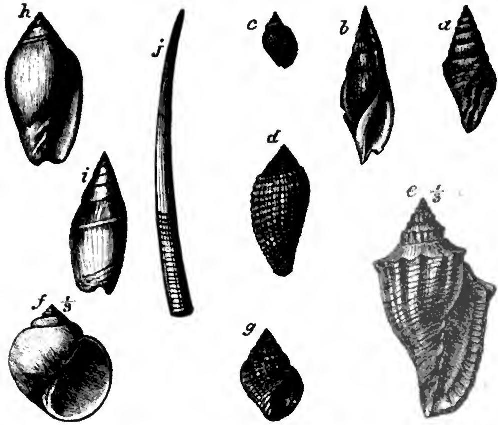
Brachiopoda.

4*c*.	Terebratula bisinuata	Dav. Brach.

Conchifera.

4 *b* and *c*.	Arca Branderi	Tab. View.
4*b*.	Cardita (Venericardia) planicosta	Tab. View.

4*c*. Chama squamosa	Foss. gr. 42, *d*.
4 *b* and *c*. Corbula pisum . . .	Foss. gr. 42, *e*.
4*c*. Crassatella sulcata	Foss. gr. 42, *f*.
4 *b* and *c*. Ostræa flabellula . . .	Foss. gr. 42, *c*.
5. Potamomya gregaria . . .	Sow. M. C., 363.



Fossil Group 43.
Middle Eocene Fossils.

a. Pleurotoma colon.
b. Rostellaria rimosa.
c. Strombus Bartonensis.
d. Voluta scabricula.
e. Voluta luctatrix.
f. Natica ambulacrum.
g. Cancellaria evulsa.
h. Oliva Branderi.
i. Ancillaria buccinoides.
j. Dentalium striatum.

Gasteropoda.

4 *b* and *c*. Ancillaria buccinoides . .	Foss. gr. 43, *i*.
4 *b* and *c*. Cancellaria evulsa . .	Foss. gr. 43, *g*.
4*c*. Conus dormitor	Foss. gr. 42, *g*.
4 *b* and *c*. Dentalium striatum . .	Foss. gr. 43, *j*.
4 *b* and *c*. Fusus longævus . . .	Foss. gr. 42, *h*.
5, 6, and 7. Lymnæa longiscata . .	Foss. gr. 44, *i*.
5. Melanopsis subfusiformis.	

4*c*. Mitra scabra	Sow. M. C., 401.
4 *b* and *c*. Murex asper	Foss. gr. 42, *i*.
4 *b* and *c*. Natica ambulacrum	Foss. gr. 43, *f*.
4*c*. Oliva Branderi	Foss. gr. 43, *h*.
5 and 6. Planorbis euomphalus	Tab. View.
? Pleurotoma colon	Foss. gr. 43, *a*.
5. Potamides (Cerithium) concavus	Sow. M. C., 339.
4*c*. Rostellaria rimosa	Foss. gr. 43, *b*.
4*c*. Strombus Bartonensis	Foss. gr. 43, *c*.
4*c*. Trochus monilifer	Sow. M. C., 367.
4*c*. Typhis pungens	Tab. View.
4 *b* and *c*. Voluta luctatrix	Foss. gr. 43, *e*.
—— scabricula	Foss. gr. 43, *d*.

Cephalopoda.

4*b*. Beloptera Belemnitoidea	Dix. Foss. Suss.

Echinodermata.

4*c*. Eupatagus Hastingsiæ	Tert. Ech.,* 26.

Fish.

4*b*. Edaphodon Bucklandi	Agassiz.
4*b*. Myliobatis Edwardsii	Dix. Foss. Suss.

Reptiles.

4*c*. Alligator Hantoniensis	Owen, Foss. Rep.
4*c*. Crocodilus Hastingsiæ	*Ibid.*
4*b*. Gavialis Dixoni	*Ibid.*
4*b*. Palæophis Typhæus	*Ibid.*

Mammalia.

5. Dichodon cuspidatus	Q. J. G. S., iv.
4*b*. Lophiodon minimus	Owen, Foss. Mam.
5. Microchœrus erinaceus	Q. J. G. S., vol. ii.
5. Paloplotherium annectens	*Ibid.*, iv.

The Upper Eocene Groups.

The fluvio-marine conditions are still continued in the Isle of Wight district without any very marked line of distinction, between the top of the Middle and the base of the Upper Eocene groups.

* Forbes's Tertiary Echinodermata, Pal. Soc.

7. THE BEMBRIDGE SERIES contains the following sub-divisions, beginning with the lowest :—

7*a*. The Bembridge limestone. A pale yellow or cream-coloured limestone, interstratified with clay or crumbling marl—the limestone full of cavities, and often quite tufaceous and concretionary, sometimes a true travertine, and sometimes conglomeritic ; contains siliceous or cherty bands in some places. Thickness, 20 to 25 feet.

7*b*. The oyster bed. A few feet of greenish sands containing oysters (*Ostræa Vectensis*) in great abundance, capped by a band of hard septarian stone, which is constant over a large area. About 10 feet altogether.

7*c*. Unfossiliferous mottled clays, alternating with fossiliferous laminated clays and marls containing *Cyrena pulchra.*

7*d*. Marls and laminated gray clays, containing *Melania turritissima.* Capped by the *Black band* forming the base of the Hempstead series.

8. THE HEMPSTEAD SERIES—the three lower divisions of freshwater and estuary origin.

8*a*. The lowest bed of this group is a firm carbonaceous laminated clay, highly fossiliferous, about 2 feet thick, known as the Black band ; over which are pale bluish and yellow shaly marls, with ironstone concretions. The whole about 40 feet thick.

8*b*. The base of this group, called the White band, is a bed of mingled broken and entire shells, more or less consolidated, often very ferruginous, from 6 inches to 2 feet thick ; over which are mottled, yellow, and pale green marls, capped by shaly clays and dark marls, and blue green ferruginous clays, with ironstone concretions. Total thickness about 50 feet.

8*c*. Variegated red and green marls and gray clays, covered by greenish clay, passing up into pale and dark gray or lead-coloured clays. Thickness about 40 feet.

8*d*. Clays with septaria, and gray and bluish clays with concretions containing abundance of *Corbula ;* marine. About 25 feet thick.

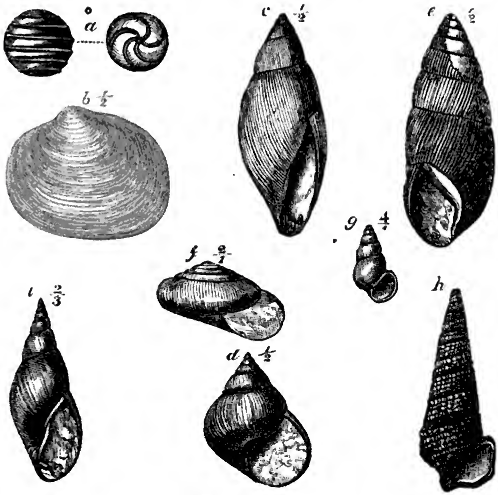
The Characteristic Fossils of the Upper Eocene Beds.

Plants.

7 and 8.	Chara medicaginula . .	Foss. gr. 44, *a*.
	Flabellaria Lamanonis . .	Brongniart.

Conchifera.

8*d*. Corbula Vectensis	. . .	Forbes, I. of W., pl. 1.*
7*c*. Cyrena pulchra	. . .	Foss. gr. 44, *b*.
7*b*. Ostræa Vectensis	. . .	Forbes, I. of W., pl. 3.



Fossil Group No. 44.
Upper Eocene Fossils.

a. Chara medicaginula.
b. Cyrena pulchra.
c. Achatina costellata.
d. Paludina orbicularis.
e. Bulimus ellipticus.
f. Helix D'Urbani.
g. Hydrobia Chastelli.
h. Cerithium elegans.
i. Lymnæa longiscata.

Gasteropoda.

7. Achatina costellata	. . .	Foss. gr. 44, *c*.
7. Bulimus ellipticus	. . .	Foss. gr. 44, *e*.
8. Cerithium elegans	. . .	Foss. gr. 44, *h*.
7. Helix D'Urbani .	. . .	Foss. gr. 44, *f*.
8. Hydrobia Chastellii	. . .	Foss. gr. 44, *g*.
7*a*. Melania turritissima	. . .	Ly. Man., fig. 182.
7. Paludina orbicularis	. . .	Foss. gr. 44, *d*.
7. Planorbis discus .	. . .	Ly. Man., fig. 187.
8. Voluta Rathieri .	. . .	Ed. Eoc. Mol.†

* Forbes's Isle of Wight, in Mems. G. S.
† Edwards's Eocene Mollusca, Pal. Soc.

Reptiles.

8. Trionyx incrassatus	Owen, Foss. Rep.

Mammalia.

7. Anoplotherium commune . .	Ly. Man., fig. 190.
7. Chœropotamus Cuvieri . .	Geol. Trans., vol. vi.
7. Dichobune cervinum . . .	Geol. Trans., vol. vi.
8. Hyopotamus bovinus . . .	Q. J. G. S., vol. iv.
7. —— Vectensis	*Ibid.*
7. Palæotherium crassum . . .	Geol. Trans., vol. vi.
8. —— magnum	Ly. Man., fig. 191.

France and Belgium.—The labours of Mr. Prestwich, continued so long and assiduously, have gradually made plain to us the correlation of the English and French Eocene beds, and joined with those of Sir C. Lyell and M. Dumont, have also taught us the relation of these with those of Belgium. The following table exhibits these relations as they are now believed to be, taking Mr. Prestwich's classification for all below the Upper Bagshot sands, and Professor Edward Forbes' for those and all above them :—

England.	Belgium.	France.
11. Hempstead.	Rupelien.	Calcaire de la Beauce. Grès de Fontainebleau. Sables et bancs de coquilles, marnes marines.
10. Bembridge.	Tongrien.	Calcaire siliceux, calcaire lacustre moyenne, Gypseous series of Montmartre, etc.
9. Osborne. 8. Headon.	Laeckenien, part of?	Calcaire marin et Grès de Beauchamp.
7. Upper Bagshot.	Système Laeckenien superieur ?	Sables moyennes, upper zone.
6. Barton clay.	Système Laeckenien inferieur ?	Sables moyennes, lower zone.
5. Bracklesham.	Système Bruxellien.	Calcaire grossier,* and Glauconie grossière.

* Mr. Prestwich gives (*Geol. Jour.*, vol. xiii. p. 99), the following detailed description of the Calcaire grossier :—

	Feet.
4. Compact white marls, passing down into alternations of greenish marls and thin yellow limestones, with seams of chert	20
3. Thin bedded fissile calcareous flags and sandstones, alternating with white marls and limestones	15
2. Thick main mass of soft, light-yellow calcareous freestone (the building stone of Paris got by mining or subterranean quarrying) passing sometimes into calcareous sands	40
1. Variable, more or less calcareous, green sands, sometimes concreted, flint pebbles often at base	25
	100

ENGLAND.	BELGIUM.	FRANCE.
4. Lower Bagshot.	Système Ypresien superieur?	Lits coquillières, and Glauconie moyenne.
3. London clay.	Système Ypresien inferieur.	Wanting.*
2. Woolwich and Reading.	Système Landenien superieur.	Grès de Pondingues, Lignites et Argile Plastique, Glauconie inferieur.
1. Thanet sands.	Système Landenien inferieur.	Wanting.

According to Mr. Prestwich, the London Tertiaries were deposited in a sea open to the north, spreading at least over south-east England, Belgium, and north of France, whilst to the south of that area dry land prevailed over the great part of the Paris Tertiary district and still farther south. Gradual depression then took place, extending the limits of the sea over the Paris area, leading to the introduction of Nummulites and more southern forms of marine life than had hitherto prevailed. Dry land was still in the immediate neighbourhood, as shewn by the occasional presence of terrestrial forms, and alternations of elevation and depression doubtless took place, modifying here and there the physical geography of the district. The Barton Clay, for instance, seems to have been deposited in a sea of a more northern character than that in which the Bracklesham clays and sand were formed. Fresh-water conditions finally became prevalent, large estuaries opened into the seas over the British and north of France areas, while large lakes existed in the centre and south of France, where, soon after, volcanic eruptions commenced to break forth, and continued for many thousand years in subsequent periods. Edward Forbes pointed out that the upper part of the Bembridge series was probably of the same age as the Molasse of Fronsadais and associated beds, and also as the Calcaire à Astéries of the south-west of France; part of the Tertiary beds of Malta, Corsica, Greece, Crete, Cerigo, south of Spain and Portugal, Azores, and North Africa, were also considered to be contemporaneous with the Hempstead series. Contemporaneous with the Hempstead also were the Molasse ossifere and the Faluns jaunes of Dax, the lower division of the Vienna Tertiaries and the marine beds, the Cerithium kalk and Upper brown coal of Mayence.—(*Mems. Geol. Sur.* 1856, p. 100.)

Sir C. Lyell, however, in his Supplement, thinks that it would be more convenient to retain a nomenclature common on the Continent,

* Some part of it, however, formerly extended into Normandy, as some clay at the top of the cliff of Ailly, near Dieppe, is believed to be London clay.—(Prestwich, *Geol. Jour.*, vol. xi. p. 230.)

and to class the Hempstead series and its contemporaneous beds as Lower Meiocene, making the beds from the Barton Clay to the Bembridge series inclusive Upper Eocene, and taking the Bracklesham and Lower Bagshot beds only as Middle Eocene. He remarks, however, that we must in this case look on the boundary between Eocene and Meiocene as an arbitrary and purely conventional line.

Certainly, as far as England (Isle of Wight) is concerned, the Hempstead beds are linked to those below by almost as great a number of species as they have peculiar to themselves.

The Alps, the Borders of the Mediterranean, Egypt, India.—Through these countries from the Alps to the Himalayas, occurring at intervals through 25° of lat. and near 100° of long., are found great masses of rock, sometimes even thousands of feet in thickness, crowded with nummulites and often almost made up of them. These are of Middle Eocene age. The summits of some of the Alps, such as the Dent du Midi and Diableretz, are formed of these beds. Associated with these are still higher beds called Flysch and Macigno in Switzerland and North Italy, and the black slates or shales of Glarus, and other beds in Switzerland, containing quantities of fossil fish, etc. The Monte Bolca fish beds are also of about this age.—(Murchison, *Geol. Jour.*, vol. v. p. 157, etc).

The Eocene beds of the Alps are not only of as great a thickness, but are as violently disturbed and contorted, and as frequently inverted, as are the older Palæozoic rocks in the mountains of Britain.

M. Alcide D'Orbigny uses the name of Suessonien (from the town of Soissons) to include the Lower Eocene beds, from which, however, he excludes the London clay, but includes the Nummulitic formation. He also gives the designation of Parisien to the London clay of England and the Paris tertiaries, from the Glauconie grossiere to the gypsum beds of Montmartre—a classification which Mr. Prestwich has shewn to be a mistake. D'Orbigny then takes the Grès de Fontainebleau as the base of his twenty-sixth stage, which he calls Falunien, subdividing it into two—Lower Falunien or Tongrien to which he assigns the Grès de Fontainebleau, and—Upper or Falunien proper, which he identifies at the same time with the Miocene of Lyell, and the Crag, which is believed to be Pleiocene.

North America.—Sir C. Lyell places the Claiborne and Alabama beds among the productions of the Middle Eocene period.

Life of the Period.

The following new generic forms now for the first time make their appearance within the British area, those apparently confined to the period being distinguished as before by an asterisk :—

Plants, *Callitrites, *Cupanoides, *Frenelites, *Hightea, *Leguminossites, *Mimosites, *Nipadites, *Petrophiloides, *Solenostrobus, *Tricarpellites, *Wetherellia, *Xulionosprionites.

Foraminifera, Alveolina, Biloculina, Globulina, *Nummulites, Operculina, Robulina, Triloculina.

Actinozoa, *Astrocænia, Balanophyllia, *Dasmia, Dendrophyllia, *Diphelia, *Holaræa, *Litharea, Mopsea, Oculina, Paracyathus, *Stereopsammia, Stylophora, Turbinolia, *Websteria.

Polyzoa and Brachiopoda, none known.

Conchifera, Cardilia, Clavagella, Cyclas, Diplodonta, Dreissena, Kellia, Glycimeris, Nucinella, Panopæa, Solen[1], Syndosmya, Teredina.

Gasteropoda, Achatina, Adeorbis, Ancillaria, Ancylus, Auricula, Bifrontia, Bulimus, Calyptræa, Cancellaria, Clausilia, Conus, Craspedopoma, Crepidula, Cuma, Cyclostoma, Cypræa, Fasciolaria, Helix, Limnæa, Marginella, Melampus, Melania,[2] Mitra, *Nematura, Niso, Odostomia, Oliva, Ovula, Pedipes, Planorbis, Pleurotoma, Pseudoliva, Pupa, Pyramidella, Ringicula, Rotella, Sigaretus, Strombus, Succinea, Terebellum, Terebra, Triton, Typhis, Volvaria.

Pteropoda, no new forms known.

Cephalopoda, *Beloptera, *Belosepia.

Echinodermata, *Eupatagus, *Schizaster, Spatangus.

Annelida, Ditrupa.

Cirripedia, Balanus.

Crustacea, *Archæocarabus, *Basinotopus.

Fish, *Acestrus, Accipenser, Ætobatis, *Ampheristus, *Auchenilabrus, *Bothrosteus, *Brachygnathus, *Calopomus, Carcharodon, *Calocephalus, *Cœloperca, *Cœlopoma, Elasmodus, *Eurygnathus, *Glyphis, *Goniognathus, *Halecopsis, *Labrophagus, *Laparus, Lepidosteus, *Loxostomus, Megalops, Merlinus, Myliobatis, Myripristis, *Naisia, *Pachycephalus, *Percostoma, *Periodus, *Phalacrus, *Phasganus, *Phyllodus, *Pisodus, *Platylæmus, *Podocephalus, *Pomophractus, Pristis, *Psaliodus, *Ptychocephalus, *Rhinocephalus, *Rhipidolepis, *Rhoncus, *Rhyncorhinus, *Sciænurus, *Scombrinus, Silurus, *Sphyrænodus, Spinax, *Teratichthys.

Reptiles, Alligator, Crocodilus,[3] Emys, Gavialis, *Palæophis, *Paleryx, Trionyx.[4]

Birds, *Gastornis (France), *Halcyornis, *Lithornis, *Protornis.

Mammalia, *Anoplotherium, *Chæropotamus, *Coryphodon, Dichobune, *Dichodon, Didelphys, *Hyænodon, *Hyopotamus, *Hyracotherium,

[1] Unless the shell called Solen, from the Carboniferous limestone, be a true Solen.

[2] Unless a doubtful species from the Carboniferous limestone be a true Melania.

[3] Unless certain fragments from the Wealden be true Crocodiles.

[4] Unless fragments from the Oolitic rocks of Scotland be those of true Trionyx.

*Lophiodon, Macacus, *Microchærus, *Palæotherium, *Paloplotherium, *Pliolophus, *Spalacodon, Vespertilio ?

The following additional genera of Mammalia have been found in rocks of this period in France, unless some of those rocks ought more properly to be called Meiocene:—

*Adapis, *Aphelotherium, *Anchilopus, Anchitherium, Canis, Cynodon, Eurytherium, *Halitherium, *Lophiotherium, Myoxus, Oplotherium, *Pachynolophus, Palæonyctis, Propalæotherium, Sciurus, *Xiphodon.

The Plants have now the general appearance of those of our own day, the fossil leaves being such as look to unbotanical eyes like the leaves of our common trees. The fruits found in the London clay of the Isle of Sheppey are some like palm nuts and some like coffee berries, and other forms, such as seem familiar to persons who have visited tropical regions.

The Foraminifera become enormously abundant in some places, whole mountain masses being almost composed of Nummulites (see Foss. gr. 42, *b*). I have seen an equal abundance of a similar form called Orbitolites (see Dr. Carpenter's papers in *Phil. Trans.*, 1856) inside the coral reefs of the north-east coast of Australia, where from depths of 10 to 20 fathoms the dredge would often come up filled with Orbitolites, while the sand of the shores of the mainland and islets was often composed of them, and I sometimes found them adhering to sea weeds, in apparently a living state, and of a delicate flesh colour in the centre. It will be recollected that a smaller form (Globigerina) is also now forming a vast foraminiferous deposit in the north Atlantic (see p. 129).

Of the Actinozoa, Professor Greene says, "The tertiary formations are abundantly supplied with Corals, chiefly belonging to the Zoantharia Aporosa and Z. Perforata. The Z. Tabulata are represented by a single genus."

Of Polyzoa no new genus seems to have first come into existence during this period, so far as the British area is concerned, if we may take the last edition of Morris' Catalogue for our guide.

Of Brachiopoda, no true generic group has originated since the Cretaceous Period, and the greater number of the known genera date from the Palæozoic epoch. The individuals, as well as the species and genera, are very rare in tertiary rocks, compared with those of the preceding epochs.

The Conchifera and Gasteropoda now become generically almost identical with those of the present time, comparatively few of our present genera not having been in existence in the Eocene Period.

The same may be said of the Cephalopodous shells, which in the

Eocene Period, as in our own day, were principally of the genus Nautilus. No Argonaut or Spirorbis, however, seems then to have existed.*

The Crustacea, the Fish, and the Reptiles, were all such as now live upon the globe, differing in species, and many of them in genus, but these differences being such as only to strike the accurate scientific observer, while their resemblances to living forms would be at once apparent to ordinary eyes.

Although we have distinct proof of the existence of large Birds and small Mammals in the Mesozoic epoch, it is in the Eocene period that we for the first time meet with the remains of Mammalia of large size and in great abundance.

The occurrence of fossil Birds must ever be rare, since the circumstances likely to cause a dead bird to sink in water so that even its bones shall be buried at the bottom, must, as observed by Sir Charles Lyell, be quite exceptional.

Owen says of the remains of Birds, that "the eocene tertiaries shew that the following ordinal modifications were at that period represented; the *raptorial*, by species of the size of our ospreys, buzzards, and smaller falcons, and most probably, also, by an owl; the *insessorial*, by birds seemingly allied to the nuthatch and the lark; the *scansorials*, by species as large as the cuckoo and kingfisher; the *rasorials*, by a species of small quail; the *cursorials*, by a species as large as, but with thicker legs than, an ostrich; the *grallatorial*, by a curlew of the size of an ibis, and by species allied to Scolopax, Tringa, and Pelidna, of the size of our woodcocks, lapwings, and sanderlings; and the *natatorial*, by species allied to the cormorant, though one of them of larger size, but less than a pelican, and also by a species akin to the divers (*Merganser*).—(*Owen's Palæontology*, p. 291.)

The list of Mammalian genera given above as belonging to the Eocene Period, is doubtless open to revision, both from palæontological and stratigraphical reasons. Nearly 50 species, however, were discovered by Cuvier in the fresh-water formations of Paris; and additions of importance have since been made by Owen and other naturalists. Most of these belonged to Cuvier's order of Pachyderms, now divided among three orders, of which the elephant, the rhinoceros, and the horse, are examples respectively.

Other Mammalia, however, have been discovered in still earlier

* The difference between *specific* and *generic* identity will, of course, be borne in mind. It is also necessary to recollect that the existing species which are found fossil do not necessarily exist in the same part of the globe as they formerly did. Mr. Godwin Austen says that not a single existing species in the Nummulitic (or Eocene) deposits now exists in any European sea (*Nat. Hist. of European Seas*, p. 251), the first appearance of the species of the European seas dating from the newer Meiocene or Pliocene period, the shells being found in the Faluns of Touraine.

Eocene beds than these, since the fossil opossum, Didelphys Colchesteri, and the fossil monkey, Macacus Eocænus, were found in the London Tertiaries. Owen's genus Coryphodon, a tapir-like animal, which must have been twice as large as the American tapir, also lived during the earlier part of the period. A skeleton found near Soissons in France, was said to have been nearly as big as a bull.—(*Owen's Pal.*, p. 325.) The Hyracotherium and Pliolophos (*ib.*) were lesser animals, with some characters more nearly approaching the hog tribe, while others resemble those of the horse, hyrax, and anoplothere.

The following abstract of Owen's notes to the third edition of Buckland's Bridgewater Treatise, will give the best general notion of some of the animals of a later part of the period.

Palæotherium.—The place of the genus Palæotherium is between the rhinoceros, the horse, and the tapir. Eleven or twelve species have already been discovered, some as large as a rhinoceros, others varying from the size of a horse to that of a hog.

Anoplotherium.—The place of this genus stands in one respect between the rhinoceros and the horse; and in another, between the hippopotamus, the hog, and the camel. Five species have been found near Paris, varying from the size of an ass to that of a hare. The largest had a thick tail equal in length to its body, like that of an otter, probably intended to assist it in swimming.

Lophiodon allied most nearly to the tapir and rhinoceros, and connected closely with the two preceding. Fifteen species have been ascertained.

Anthracotherium, so called because first found in the lignite of Cadibona in Liguria, had seven species—some of them like a hog in size, others as large as a hippopotamus.

Chæropotamus was allied to the hogs, in some respects approaching the Babiroussa, and forming a link between the Anoplotherium and the Peccary.

Adapis seems to have formed a link between the Pachydermata and the Insectivorous Carnivora; it was like a hedgehog in form, but three times its size.—*(Owen in Buck. Bridge. Treat.)*

The genera Dichodon, Dichobune, Xiphodon, Microtherium, etc., were smaller and more delicate animals, allied to those above mentioned, but having some affinity to the Chevrotains of the East.

Contemporary with these animals that seem to have been adapted for a life in the marshy grounds on the borders of lakes, were several carnivorous animals, to whom they served for food. Of these, the Hyænodon is an example, an animal of the size of a leopard, one of those which, to judge from the character of their flesh-cutting teeth, were more fell and deadly than the modern wolves or tigers.—(*Owen's Pal.*, p. 339.)

Extinction of Life at the Close of this Period.—The only generic forms mentioned in Morris's catalogue as dating from a pre-Tertiary Period, and surviving into the Eocene and then becoming extinct, are the following :—

Plants, Flabellaria, Lycopodites.
Foraminifera, Frondicularia, Marginulina.
Fish, Cœlorhyncus, Cr.; Edaphodon, Cr.; Gyrodus, O.; Hypsodon, Cr.; Notidanus, Cr.

CHAPTER XXXVI.

THE MEIOCENE PERIOD.

The proportion of living to extinct species is taken at about 25 per cent. If we include the Hempstead series in the deposits of the Eocene period, we have no stratified rocks in the British Islands representative of the formations of the Miocene period, unless it be the "ash" beds and lignites associated with the basalts of the north of Ireland and west of Scotland.

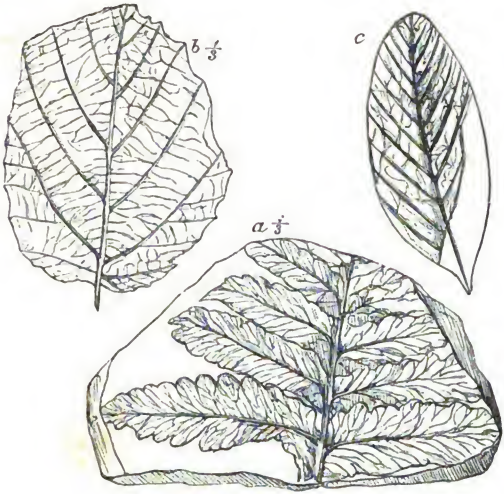
The Duke of Argyle has described (in *Qr. J. Geol. Soc.*, vol. vii.) the interstratified traps, ashes and leaf beds to be seen in the island of Mull, one of the Hebrides, of which the islet of Staffa is a dependency. The headland of Ardtun exhibits the following section of these deposits:—

	Feet.
8. Uppermost basalt	40
7. First leaf bed	2
6. First ash bed	20
5. Second leaf bed	$2\frac{1}{2}$
4. Second ash bed	7
3. Third leaf bed	$1\frac{1}{2}$
2. Amorphous basalt	48
1. Columnar basalt (to low tide level) . .	10
	131

The Ash beds are described as resembling the tuffs of Mont Dor, Vesuvius, and Madeira; the leaf beds as baked clay, or very fine mud containing impressions of leaves, and sometimes consisting of a mere mass of compressed leaves still retaining the "damp obscure colours of vegetable decay." A seam of coal was found in one place immediately under a sheet of basalt, and this is believed to be the extension of one of these leaf beds. Equiseta stems are mentioned as well as the leaves, and the whole deposits are conjectured to have been formed in a shallow lake or marsh over which the igneous rocks have been ejected.

A conglomerate of burnt red and yellow Chalk flints is mentioned as associated in one place with the first ash bed (No. 6.)

The leaves were examined by Professor Edward Forbes, who says of them :—" The general assemblage of leaves is decidedly Tertiary, and most probably of that stage of Tertiary termed Meiocene. Their climatal aspect is more mid-European than that of our Eocene flora. There is a striking resemblance between some of them and fossils from Styria and Croatia."



Fossil Group No. 45.
Fossil leaves from Island of Mull.
a. Filicites ? Hebridicus.
b. Alnites ? Macquarii.
c. Rhamnites ? multinervatus.

Besides the genera mentioned above, Forbes referred others to Taxites ? Platanites, and Equisetum.

The general resemblance between these deposits and those of Antrim is noted by the Duke of Argyle, who quotes from Mr. J. Nasmyth an account of the cliffs near the Giant's Causeway, to the general accuracy of which recent observation enables me to bear testimony. Over the Chalk in that district there is a thickness of nearly 500 feet of beds of interstratified basalt and ash. Some of the basaltic beds

are regularly columnar with cup and ball articulations, others, like starch, irregularly columnar without articulations, some amorphous, and of these many are a green amygdaloidal rock full of cavities and veins of zeolites, many of which are formed in the joints of the rock, and are thus of obviously subsequent origin to the rock itself.

One or two of the ash beds are very regular, and persistent for a long distance, and well seen in consequence of their being of lighter and brighter colours than the other rocks. They contain nodular concretions of red pisolitic oxide of iron, from which they are often spoken of as red ochre beds.

Near the summit of the cliff over the Giant's Causeway, beneath a wall of rudely columnar basalt 50 feet high, is a little rather irregular seam of gray fire-clay, and in that or over it is an irregular band of coal or lignite, of which I only succeeded in digging out some broken fragments that had no appearance of structure, but which Mr. Nasmyth says sometimes shews the fibres of dicotyledonous wood like recent charcoal. The guide assured me that the country people sometimes found whole trees in this bed. Similar beds of lignite, but of greater extent, are, I believe, found near Ballymena, and in other parts of county Antrim.

Dr. Berger in 3d vol. *Geol. Trans.*, 1st series, says, that the maximum thickness of the Antrim basaltic formation is 900 feet, that its average thickness may be taken as 545 feet, and its extent at 800 square miles. From Sir R. Griffith's map its area would appear to be at least 1200 square miles, as it occupies a quadrangular space 48 miles long from north to south, and 28 miles wide from east to west.

In fig. 122 we have a diagrammatic section through Cave Hill and across the valley of Belfast. In this section the Basaltic formation is seen resting on the Cretaceous beds. Just at the base of the basalt is a little bed of brown clay, full of chalk flints burnt red or yellow. This appears to have been the muddy deposit derived from the waste of the Chalk, and most probably to have formed the sea-bottom on which the first outpourings of igneous matter were deposited. I did not succeed in discovering any organic remains in it, but should hope that some may eventually be found, and also that leaves or other fossils may be found in some of the ash-beds or other parts of the formation. This clay is well seen also at Ballycastle, and doubtless occurs in other places. Some of the clay beds near the Giant's Causeway might contain fossils.

The dykes represented in fig. 122 are excessively numerous in the country about the basalt, both on the north coast and near Belfast, and probably in other parts. On the shores of Belfast Lough they form straight causeways, standing up as vertical walls, several feet high, exactly as if they were artificial quays. The slopes of the Cave Hill

are traversed by dykes, some of which can be traced up from the coast and seen in the Chalk quarries, cutting in black vertical seams through the white limestone in a most picturesque manner. These dykes are probably in many cases the feeders from which some of the basaltic beds above may have boiled over while the rock was molten, though in other cases they may not perhaps have succeeded in reaching the surface.

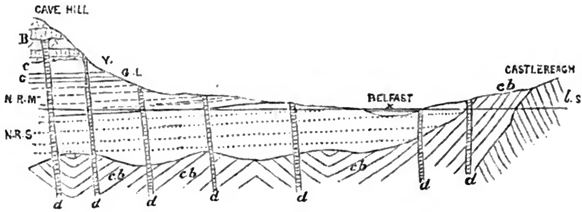


Fig. 122.

Diagrammatic Section across Belfast Valley.

		Feet.	
B. Basalt, some columnar beds, some amygdaloidal		up to 900	Tertiary.
Y. Eroded surface of chalk, with clay full of flints baked by basalt.			
C. Chalk	in some places as much as	250	Cretaceous.
G. Greensand	not exceeding	25	
L. Lias	never exceeding	30	Oolitic.
N. R. M. New red marls, with beds of rock salt	about	600	Trias.
N. R. S. New Red Sandstone	about	600	

c b. Carboniferous rocks, undulating at high angles, probably with small basins, some of which may contain beds of coal. The lower beds only visible on east side of the Lough.

l. s. Lower Silurian, black slates, etc., dipping at high angles to east, away from the Carboniferous rocks.

d. Dykes of basalt.

× Clay and silt, with bed of peat below, filling up head of Belfast Lough.

These are the only rocks in the British islands that can be even conjectured to belong to the Meiocene Period, unless we adopt the continental classification, and consider the gypseous series of Montmartre the uppermost of the Eocene beds, in which case we must also take the equivalent Bembridge series of the Isle of Wight as the uppermost of the Eocene, and include the Hempstead beds and their equivalents among the Meiocene deposits. There is, it appears, a palæontological reason for this arrangement on the Continent, inasmuch as if we draw the line at the top of the Montmartre beds, and at the base of the

Calcaire lacustre superieur (or Calcaire de la Beauce), certain generic and even specific forms of Mammalia are kept wholly within the Meiocene groups, which otherwise would be made common to the Eocene and Meiocene periods. The genera Dorcatherium, Cainotherium, Anchitherium, and Titanomys, and the species Rhinoceros incisivus, and others, are examples.—(M. Lartet, in *Lyell's Supplement.*)

Belgium and France.—The Limburg beds, the Rupelien of Dumont, the Bolderburg beds, the Faluns of Touraine and Bourdeaux, the Falunien superieur of D'Orbigny, including the principal part of the lacustrine strata of Auvergne and central France, are included in this period by Lyell. Associated with the latter were the earliest beds of lava and volcanic breccias which began now to be poured forth in the districts of Auvergne* and Velay, and continued to break forth at intervals to later times.

Germany and Switzerland.—The Mayence basin, the principal part of the Vienna basin, part of the Molasse of Switzerland, containing the "Nagel-flue," a conglomerate 6000 or 8000 feet thick, are classed as Meiocene.

Nothing is more calculated to strike the geological traveller on his first visit to Switzerland than the vast deposit of the "Molasse," occupying the central region between the Alps and the Jura. This is the country of the great lakes, extending from that of Geneva to that of Constance. The level of those two lakes is from 1100 to 1225 feet above the sea, that of the Brienzer Zee is nearly 1800, the other large lakes being of intermediate heights. The hills by which these lakes are environed have all the rugged and broken character of mountains, and rise into peaks of various altitudes up to that of 6050 feet, which is the height of the Rhigi Kulm. These hills which, if they were not overshadowed by the still loftier Alps, would themselves be celebrated mountains, are composed from top to bottom of beds of sand and gravel, occasionally compacted into sandstone and conglomerate, of more recent origin than the newest beds of the Isle of Wight. Their thickness is equal to that of one of our Palæozoic groups, the conglomerate, called Nagel-flue, forming all the upper part of the Rhigi, being itself stated at 6000 feet thick.

The following groups of beds are also classed as Meiocene by Sir C. Lyell.

Italy.—Part of the beds in the hill of Superga, near Turin.

North America.—The sands of Richmond, and the James River in Virginia.

* The great volcanic mountains of the Cantal, and that of the Mont Dor in Auvergne are of far earlier date, as may be surmised from the worn and eroded condition of their flanks, and the destruction of their central cones and craters, when compared with the perfect state of the volcanoes that are probably of Meiocene age.

India.—The Sewalik formations, which compose the sub-Himalayan range of hills.—(*Lyell's Manual.*)

Characteristic Fossils.—I shall not pretend to give lists of these. Sir C. Lyell says that the fossils of the "faluns" have a more extra-European facies than those of the Crag presently to be described. They contain seven species of Cypræa, some larger than any Mediterranean cowry, and several species of the genera Oliva, Ancillaria, Mitra, Terebra, Pyrula, Fasciolaria, and Conus. There are eight Cones, some very large, and the species of Nerita are more like those of the tropics than of the Mediterranean. Out of 290 species of shells collected by Sir C. Lyell to the south of Tours, 72 only could be identified as living species, which is about 25 per cent; among a total of 302 in his possession, 45 only are to be found in the Suffolk Crag, or 15 per cent; and a similar small per centage in the Actinozoa and Polyzoa. If we compared the fossils of the "faluns" with those of living British species, we should doubtless have very few in common, the living species found in the Faluns being to be sought in more tropical provinces, while those of the Crag have a more northern "facies" impressed upon them. The Faluns have a few terrestrial species of shells, among which is the Helix turonensis and remains of Mammalia belonging to the genera Deinotherium, Mastodon, Hippopotamus, Chœropotamus, Dichobune, Deer, and others, together with some Cetaceans and Phocidæ, Lamantine, Morse, etc.—(*Lyell's Manual*, p. 180, etc.)

The very remarkable animal Deinotherium giganteum is characteristic of the Meiocene beds of Europe, while another species, D. Indicum, has been found at Perim Island in the Gulf of Cambay, and at Attock in the Punjaub.

In the Sewalik Hills of India, Dr. Falconer and Colonel Cautley found, together with portions of Mastodon, five extinct elephants (three of them, Stegodon, intermediate between Elephas and Mastodon), a Hexaprotodon (extinct hippopotamus), a Chalicotherium and extinct Giraffe, a Camel and large Ostrich, the very remarkable genus Sivatherium, together with Carnivora and Monkeys, great Crocodiles, and a Tortoise (*Colossochelys atlas*), the curved shell of which was 20 feet across. Fifteen species of fresh-water shells also occur, of which all but four are extinct, giving a percentage of about 25 : 100.—(*Lyell's Supplement.*)

In North America are many shells of the genera Natica, Fissurella, Artemis, Lucina, Chama, Pectunculus and Pecten, and one, Astarte undulata, very like the A. bipartita of the Suffolk Crag. "Out of 147 of these American fossils, I could only find thirteen species common to Europe, and these occur partly in the Suffolk Crag and partly in the Faluns of Touraine; but it is an important characteristic of the American group that it not only contains many peculiar extinct forms,

such as Fusus quadricostatus and Venus tridacnoides, abundant in these same formations, but also some shells which, like Fulgur carica and canaliculatus, Calyptræa costata, Venus mercenaria, Modiola glandula, and Pecten magellanicus, are recent species, yet of forms now confined to the western side of the Atlantic—a fact implying that some traces of the beginning of the present geographical distribution of Mollusca date back to a period as remote as that of the Meiocene strata."—(*Lyell's Manual*, p. 182.)

The Tertiary beds of Malta, which may be of Meiocene age, contain among many others the following fossils :—

Foraminifera, Lenticulites complanatus.
Brachiopoda, Terebratula ampulla.
Conchifera, Ostræa Virleti, Ostræa Bablayei, Pecten Brudigalensis.
Gasteropoda, Scalaria Duciei, Scalaria retusa.
Cephalopoda, Nautilus ziczac ? ?
Echinodermata, Clypeaster altus, Schizaster Parkinsoni, Scutella subrotunda.
Fish, Carcharodon megalodon, Hemipristis serra, Oxyrhina xiphodon.
Mammalia, Delphinus, Halitherium.

LIFE OF THE PERIOD.

Space forbids the discussion of this subject at any length. I shall therefore confine myself to a few notes on some of the Mammalia—derived chiefly from Professor Owen and Dr. Falconer.

Two Monkeys, Pliopithecus antiquus and Dryopithecus Fontani, have been detected in beds believed to be Meiocene.

The Proboscidean animals came into existence ; being now represented, as shewn by Dr. Falconer (*Q. J. Geol. Soc.*, vol. xiii.), in their three great divisions, Dinotherium, Mastodon, and Elephas.

The Dinotherium seems to have been something like an aquatic elephant, with some affinity to the Tapir in his teeth ; his tusks growing with a downward curve from his *lower* jaw, as if for the purpose of grubbing up water plants (see fig. in *Buckland's Bridgewater Treatise*).

The Mastodons were like Elephants, but were of a more omnivorous character, as shewn by their rough mammillated teeth, from which they derive their name. Falconer divides them into those whose central* teeth were crowned with three transverse ridges (Trilophodon), and those with four (Tetralophodon). He mentions four Meiocene species in Europe, of which M. (Trilophodon) angustidens† is the

* That is the last of their milk molars and the two first of their true molars.

† Other Mastodons, both from other countries and from later formations, have been previously referred to this species, but Dr. Falconer shews that this has been done by mistake, and that the true M. angustidens is only Meiocene and European.

best known, and three in India, of which M. (Tetralophodon) latidens is one.

He subdivides the genus Elephas into three sub-genera, according to the structure of their teeth—viz., Stegodon, intermediate between Mastodon and Elephas, the group being now wholly extinct ; Loxodon, of which the African elephant is a species ; and Euelephas,* of which the Asiatic elephant is one. None of these appear to have lived during the Meiocene period in Europe, but in India there were four species of Stegodon, which are all the species known, and *one* of Loxodon, and *one* of Euelephas.

Of the Cetacean order, Owen describes the carnivorous whale Zeuglodon, of which some specimens have been brought from Malta, and the entire skeleton, 70 feet long, found in Alabama. The Sirenia also were represented by a kind of Dugong called Halitherium.

The Edentata were also represented in Europe by a form intermediate between the Asiatic Manis and African Orycteropus. It is called Macrotherium from its great size, which Cuvier at one time believed must have reached a length of 24 feet.

The Deer tribe (Cervidæ) seem to date their existence from the Meiocene period.

Contemporaneous with these animals were Carnivora, such as the Amphicyon, a forerunner of the Plantigrade family, and the Machairodus (or sabre tooth), first found in the Meiocene beds of Auvergne and Epplesheim. Some species were as large as a lion, others of the size of a leopard, and their teeth shews them to have been as powerful and ferocious as those of our own time.

Of other animals, Owen says :—" Our knowledge of the progression of Mammalian life during the Meiocene period teaches us that one or two of the generic forms most frequent in the older tertiary strata still lingered on the earth, but that the rest of the Eocene mammalia had been superseded by new forms, some of which present characters intermediate between those of Eocene and those of Pleiocene genera. The *Dinotherium* and narrow-toothed *Mastodon*, for example, diminish the interval between the *Lophiodon* and the *Elephant ;* the *Anthracotherium* and *Hippohyus* that between *Chœropotamus* and *Hippopotamus ;* the *Acerotherium* was a link connecting *Palæotherium* with *Rhinoceros ;* the *Hippotherium* linked on *Paloplotherium* with *Equus*."—(*Owen's Pal.*, p. 343.)

Dr. Falconer points out that the *Mastodon angustidens* is associated

* In Stegodon a vertical longitudinal section of the tooth would shew the thick transverse plates of enamel arranged like gables, with the space between each gable partly filled with dentine. In Loxodon the horizontal section of the tooth, or its natural surface, shews the plates of enamel disposed in lozenge-like forms, while in Euelephas these are narrow transverse plates with parallel sides.

with peculiar species of some of the above-named Meiocene genera, and others, such as *Mastodon tapiroides*, *Chalicotherium Goldfussii*, *Anchitherium Aurelianense*, *Rhinoceros Sansaniense*, and several others, at three well marked localities, namely, in the Falunian deposits of Touraine, in the upper fresh-water Molasse of Switzerland, and in the sands of Epplesheim.

The peculiar assemblage of species in these cases shews that the animals were contemporaries during the Meiocene period, and that their remains may be taken as characteristic Meiocene fossils. If that be taken as granted, it would seem that the superficial and recent looking torrential deposits, described by M. Gaudry as being found in the Pikermi valley, at the foot of Pentelicus, four hours north-east of Athens, must be of Meiocene age, since they contain numerous bones of the above-mentioned animals and others, such as Helladotherium, Metarctos, and Thalassictis.—(*D'Archiac, Comptes rendus, Nov.* 11, 1861).

In speaking of many of the extinct genera and species of animals as forming links between our existing forms, we must never forget that the living forms are not the types, but the variations from the types. Mr. Woodward, in his Manual of the Mollusca, well observes that "a three-toed horse (Hippotherium) would now be looked on as a *lusus naturæ*, but in truth the ordinary horse is far more wonderful." We are apt to assume that the forms with which we are most familiar are the most simple and natural, but the scientific naturalist often finds some extinct form as the simple archetype from which numerous others have departed more and more by variation and combination of parts in subsequent periods. Hence we often have to speak of extinct animals as holding an intermediate place between some existing forms.

CHAPTER XXXVII.

THE PLEIOCENE PERIOD.

OF this period we again have representatives, though small ones, in the British Islands. On examining Professor Ramsay's Geological Map of England and Wales, it will be seen that the chocolate colour, numbered 22, representing the Lower Eocenes, is covered in the Hampshire basin by lighter tints, numbered 23 and 24, representing the Middle and Upper Eocenes. Patches of the Middle Eocene colour occur also to the west of London; but on tracing the dark colour north-eastwards into Suffolk, it is covered by a deposit, denoted by a different tint, and numbered 25. This deposit not only lies on these Lower Eocene beds, but overlaps and stretches beyond their termination on to the Chalk of Norfolk. These uppermost beds consist of an assemblage of sands and gravels, which are locally termed Crag, and they have lately been divided into three groups, on account of the different assemblages of organic remains which they contain. Two of these may be assigned, without doubt, to the Pleiocene period, as containing a plurality of recent species, though still mingled with a large minority of extinct forms.

TYPICAL GROUPS OF ROCK.

Britain.—The two Pleiocene groups are the following :—

	Feet.
2. Red Crag	50
1. Coralline Crag	40

1. THE CORALLINE* CRAG is composed chiefly of soft marly sands of a white colour, sometimes speckled with green, containing occasionally thin bands of flaggy limestone. It is generally about 20 feet, but sometimes as much as 50 feet in thickness. Near Ipswich it has been denuded, and the Red Crag is seen to lie in the hollows that have been eroded in it, which is the only direct evidence of the superposition of the Red Crag on the Coralline; otherwise they lie side by side, the

* It appears that this term Coralline, although now settled by usage, was in reality a mistake, inasmuch as true Corals are rare in the Crag, and the coral-like bodies found abundantly in the "Coralline," but not entirely absent from the "Red" Crag, are not in reality *Actinozoa* but *Polyzoa*.—(*Palæontog. Soc.*, Edwards and Haime).

Coralline Crag being confined to a strip of country twenty miles long by three or four wide, stretching through Ipswich from the Stour river to the Alde river.

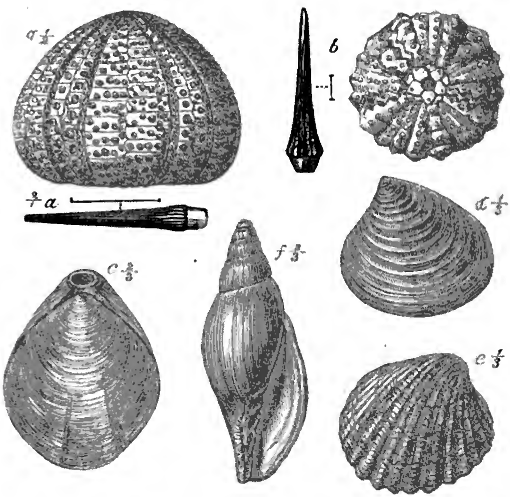
2. The Red Crag consists of beds of red quartzose sands and gravel, with accumulations of rolled shells. It is very variable in character, sometimes regularly stratified, sometimes more confused.

Both groups resemble the deposits which we may now suppose to be taking place in the shallow bed of the German Ocean.

Characteristic Fossils of the Coralline Crag.

Foraminifera.

Operculina complanata.



Fossil Group No. 46.
Coralline Crag Fossils.

a. Echinus Woodwardii.	*d.* Astarte Omalii.
b. Temnechinus excavatus.	*e.* Cardita senilis.
c. Terebratula grandis.	*f.* Voluta Lamberti.

Actinozoa.

Flabellum Woodii . . . . . Br. Foss. Cor.

Polyzoa.

Cellepora cellulosa	Busk's Crag. Pol.*
Theonoa globosa	*Ibid.*

Brachiopoda.

Terebratula grandis (and Red Cr.) . .	Foss. gr. 46, *c.*

Conchifera.

Astarte Omalii (and Red Cr.) . .	Foss. gr. 46, *d.*
Cardita senilis (and Red Cr.) . .	Foss. gr. 46, *e.*
Coralliophaga cyprinoides . . .	Wood, Crag Mol.†
Cyprina rustica	Tab. View.
Ostræa princeps (and Red Cr.) . . .	Wood, Crag Mol.
Pecten Gerardi	Tab. View.

Gasteropoda.

Bullæa sculpta	Wood, Crag Mol.
Cassidaria bicatenata	Tab. View.
Voluta Lamberti	Foss. gr. 46, *f.*

Echinodermata.

Comatula Brownii	Forbes, Ter. Ech.
Echinus Woodwardii	Foss. gr. 46, *a.*
Temnechinus excavatus	Foss. gr. 46, *b.*

Characteristic Fossils of the Red Crag.

Foraminifera.

Polymorphina communis . . .	(Living.)

Actinozoa.

Balanophyllia calyculus	Foss. gr. 47, *a.*
Echinocyamus pusillus	Foss. gr. 47, *b.*

Conchifera.

Artemis lentiformis	Tab. View.
Astarte obliquata	Foss. gr. 47, *c.*
Cardium angustatum	Foss. gr. 47, *d.*
Mactra constricta	Foss. gr. 47, *e.*
Pecten plebeius	Tab. View.
Pectunculus variabilis	Tab. View.

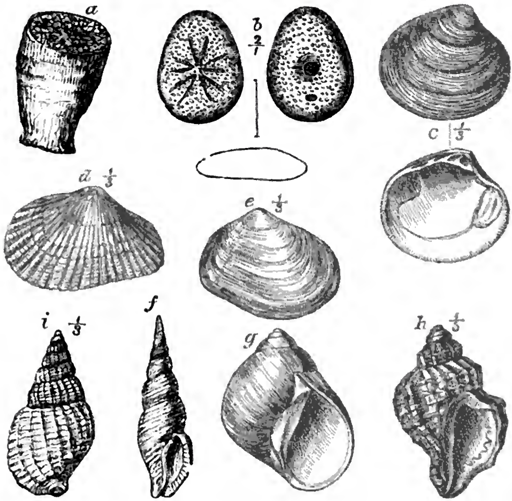
Gasteropoda.

Columbella sulcata	Foss. gr. 47, *f.*
Cancellaria costellifera	Tab. View.

* Busk's Polyzoa of the Crag, Pal. Soc.

† The Mollusca of the Crag, by Mr. Searles Wood, Pal. Soc.

Fusus antiquus	Tab. View.
—— contrarius	Tab. View.
Nassa reticosa	Foss. gr. 47, *i.*
Natica hemiclausa	Foss. gr. 47, *g.*
Purpura tetragona	Foss. gr. 47, *b.*
Scalaria Grœnlandica	(Living).



Fossil Group No. 47.
Red Crag fossils.

a. Balanophyllia calyculus.
b. Echinocyamus pusillus.
c. Astarte obliquata.
d. Cardium angustatum.
e. Mactra constricta.
f. Columbella sulcata.
g. Natica hemiclausa.
h. Purpura tetragona.
i. Nassa reticosa.

Mammalia.

Balænodon emarginatus (ear-bones) .	Tab. View.
Felis pardoides	Owen, Foss. Mam.
Mastodon Arvernensis (angustidens) .	*Ibid.*

There are many fossils common to the Coralline and Red Crags.

some of which lived in both periods, but others may possibly have been washed as fossils from the Coralline into the Red Crag. There are also fossils common to the two Crags and to more recent deposits, and it is obviously likely that the still existing species found in either of the Crags will also be found in any or all subsequent deposits, either in the British area or elsewhere, according to their subsequent migrations.

Of the living species that are found in the Red Crag but not in the Coralline or any earlier deposit, it is noteworthy, that they have a rather more northern character than the fossils of the Coralline Crag have, many of them still inhabiting our own coasts. Others, however, with many of the living species of the Coralline Crag, are now only to be found in more southern seas.

Antwerp.—Sir C. Lyell (*Manual*, p. 174) describes strata around Antwerp and on the banks of the Scheldt below that city, containing 200 species of shells, of which two-thirds are the same as those of the Crag of Suffolk. More than half are living species, principally belonging to the Celtic, though some are Lusitanian (Mediterranean) species.

Normandy.—The same authority mentions a patch of Crag near Valognes in Normandy, and at other places, extending to a little south of Carentan, but none farther.

Italy.—The sub-Apennines, or low hills intervening between the Apennines and the sea, on each side of Italy, are made of Tertiary strata, of which part are of Miocene, part of Pliocene, and part of a still more recent period. The beds of Asti and Parma, and the blue marl of Sienna, which near Parma is 2000 feet thick, over which are yellow sands and conglomerates formed on the shallowing of the sea, belong to this period, as do the Tertiary marine beds forming the base of the seven hills of Rome.

S. Russia.—Sir R. I. Murchison and M. de Verneuil describe limestone and sands rising occasionally to the height of several hundred feet above the sea around the coasts of the Caspian and Aral seas, and the North-western parts of the Black Sea, as belonging to this period. They call them the Aralo-Caspian formation. The fossils are partly fresh-water, partly marine.—(*Geology of Russia.*)

Life of the Period.

It will be best not to attempt to discuss this problem with respect to this period only, but to give a summary of what is known of Pliocene and Pleistocene life at the close of the next chapter.

CHAPTER XXXVIII.

PLEISTOCENE PERIOD.

Without attempting to draw any very nice or accurate distinction between the deposits of this and the preceding period, we may take, as a rough definition of the Pleistocene deposits, "those in which more than three-fourths of the fossils are of existing species."

TYPICAL GROUPS OF ROCK.

BRITAIN.—*Norwich, or Mammaliferous Crag.*—There are in the neighbourhood of Norwich certain beds of sand and gravel which go by the name of Crag, as well as the earlier deposits described in the preceding chapter. They contain both fresh-water and marine shells, and the bones of Mammalia, especially those of Elephants, and a Mastodon, which, according to Dr. Falconer, unite it closely with the Red Crag. Mya lata and Nucula Cobboldiæ (*Tab. View*), are two extinct shells found in those beds.

High Level Gravels.—In the south of England the higher grounds are covered by a deposit of sand and gravel, consisting largely of rolled chalk flints. It is believed that this deposit was spread out on the surface of the ground before the formation of the present valleys.

No fossils have been found in the high level gravels, and Mr. Godwin Austen supposes that they may be of any age between that of the uppermost Eocenes and the Crag. (See his paper *On the tertiary deposits of the Sussex Coast, etc., Q. J. Geol. Soc.*, vol. xiii. p. 70.)

GLACIAL DEPOSITS.—*Drift, Northern Drift, Boulders and Boulder Clay or Till, Erratic Blocks, Limestone Gravel and Eskers of Ireland, Kames of Scotland.*—Over the lower lands of Scotland and Ireland, and the northern part of England, as far south as Cambridge and Essex, and the northern margins of the Thames valley, there are superficial deposits of much interest, which go by the different names mentioned above.

Drift Gravels.—This is a term a little liable to mislead, because some of the superficial gravels of the Midland Counties of England are

the slightly inclined outcrops of the unconsolidated conglomerates of the New Red Sandstone. Others again, are believed to be gravels of the Cretaceous or other periods.

Boulder Clay or Till.—This deposit, however, is not at all likely to be confounded with any other. It consists of a mass of unstratified dark chocolate brown clay, or sometimes red clay, with blocks and boulders of stone stuck in it promiscuously, the whole seeming to be the result of an irregular pell-mell hurrying forward and deposition of the materials.

Beds of sand and gravel, however, occur in it here and there containing shells. Mr. James Smith, of Jordan Hill, mentions some, near Glasgow, up to heights of more than 500 feet above the sea, some of the shells being of northern or arctic species (*Q. J. G. S.*, vol. xii., p. 386). Sea shells have also been found in it in other localities in England and Wales, and some belonging to this deposit were found by the late Mr. Trimmer on Moel Tryfaen, near Bangor, at a height of 1400 feet above the sea.

Professor Ramsay describes the drift of Caernarvonshire as stretching with a gentle slope up the valleys of the mountains of Snowdonia, even to heights of 2300 feet (*Q. J. G. S.*, vol. viii., p. 372), precisely in the same way that similar deposits occur in the mountain valleys of Ireland.

The shells found in these glacial deposits are mostly living species, but some of them now live only on the coasts of Iceland, Greenland, or Spitzbergen, while others are such as are found on the northern coasts of our own islands.

The boulders or rounded blocks of rock are usually derived from places to the northward of the spots where they are now found, and sometimes very far to the northward. Blocks of Scotch rocks are found in England. Blocks of rock readily identifiable with those existing in situ in Cumberland and Westmoreland, may be traced in enormous abundance through Lancashire, Cheshire, and Shropshire, gradually dying away in Worcestershire and Gloucestershire. They may be found buried in the Boulder Clay, as far as that extends, and also loose, scattered over the country, on the hill tops or in the valleys, and spreading high up on to the flanks of the Welsh mountains on the one hand, and on to the flanks of the Pennine chain that runs from Derbyshire into Scotland, on the other. Wasdale Crag, near Shap, is formed of a very peculiar porphyritic Granite with large crystals of red feldspar; and blocks of this, together with many other kinds of rock, have been carried across the deep vale of Eden on to the flanks of the Pennine chain, and even across it, especially over the pass of Stanemoor, which is 1440 feet above the sea, but is right opposite Wasdale Crag. Thence they have been distributed over the lower parts of Durham, and down the vale of York, to the east coast of England.

Phillips mentions also a curious conglomerate, called "brockran," lying in the New Red or Permian rocks, in the bottom of the vale of Eden, blocks of which have also been lifted up and carried over Stanemoor. —(*Phillips's Manual*, p. 422.)

The direction in which the blocks of rock have been carried is not always due south, although the prevailing direction is southerly. They sometimes have travelled even towards the north, both in the north and centre of England. Blocks of Cumberland rocks have been carried across the Solway Frith into Scotland, according to Professor Sedgwick, and I have seen blocks of the Charnwood forest rocks in Leicestershire, a few miles to the north of the forest, although they are not so large, so numerous, or so far travelled as those which may be found to the south of it.

Ireland.—The centre of Ireland is chiefly a great plain of Carboniferous limestone, partly surrounded by several groups of lofty hills, composed of the older rocks, which rise from beneath the limestone. The hills to the south of this plain have every height, up to 3000 feet above the sea. Other hills, rising to heights of 800 and 1000 feet, are composed of Coal-measures lying on the limestone ; these are surrounded by valleys which are branches of the limestone plain. The general level of the limestone plain is from 100 to 300 feet above the sea, only a few isolated hills of limestone in the interior of the country rising to as much as 500 or 600 feet.

The low country is largely covered by a widely spread mass of Drift, consisting of dark sandy clay, with pebbles and blocks, and occasional beds of sand and gravel, sometimes very regularly stratified. The great majority of the pebbles are rounded fragments of Carboniferous limestone, whence the deposit usually goes by the name of the Limestone gravel.

This deposit rests not only on the limestone, but sweeps up on to the flanks of all the hills, both those which are made of the Lower Palæozoic rocks and those formed of the Coal-measures. In each case the Limestone gravel becomes largely mingled with the detritus of the rocks of which the hills are made, and sometimes to such an extent that the local rocks assume a decided preponderance, and occasionally compose almost the whole of the deposit.

The Limestone gravel is found in considerable abundance, however, and almost entirely composed of limestone pebbles, up to heights of 1200 feet on the Granite mountains south of Dublin (see *Explanation of sheets* 102 and 112, *Geol. Soc. Jour.*, and paper by Mr. Kelly in *J. Geol. Soc. Dub.*, vol. vi.) In the lower part of Glenismaule, from which the river Dodder issues on to the plain, and also on the shore at Salthill, near Kingstown, and at other places, it is bound into a firm conglomerate by veins of fibrous arragonite.

The Limestone gravel spreads across the lower part of the Granite range, and runs down by Bray into the County Wicklow, where it is covered by beds of sand and marl that spread through Wicklow and Wexford over all the low grounds between the mountains and the sea coast. In the recent railway cutting near Wicklow, I found (in 1861) blocks of limestone, a foot in diameter, in clay in the lower part of the cutting. This clay formed a mass forty or fifty feet thick, with sand over it and on each side of it, which contained layers of small limestone pebbles, and also broken pieces of lignite. The sand might possibly be of subsequent origin, and the limestone pebbles derived from the clayey Drift. The large pebbles of the beach, however, which now fronts the shore of Wicklow for at least ten miles from Greystones to Wicklow Harbour, are principally of dark limestone, and seem to be now continually travelling from north to south along the shore.

Chalk flints and pieces of hard Antrim chalk are found in the Drift in the counties of Dublin and Wicklow up to heights of one or two hundred feet, and along the whole eastern and southern coast of Ireland, at least as far as Ballycotton Bay on the coast of Cork.

Fragments of sea shells are found in the Limestone gravel in Glenismaule, near Dublin, and also in the Dargle valley and in the valley west of the Sugar Loaf, and south of Enniskerry, county Wicklow, up to heights of 500 or 600 feet, but they have not yet been recorded from any greater height.

They are found in greater abundance and much better preservation in the sands and marls which overlie (or form the upper part of) the Limestone gravel through the lower parts of the county of Wexford (see Appendix to Edward Forbes's paper on *Fauna and Flora of British Isles, Mems. Geolog. Sur.*, vol. i.) They are also to be found in the gravels of the more central parts of Ireland, as at Ballymore Eustace in Kildare, as I am informed by Mr. R. Callwell. Like the shells of the drift deposits in England, they are almost all of existing species, generally with a northern or Arctic or Boreal facies. But, in the southern part of Wexford, Colonel Sir H. James formerly found fragments of shells (*Nucula Colboldii, Fusus contrarius, Turritella incrassata*, and a *Mitra* allied to a Spanish species) which make it probable that the limit of the northern species ran thereabouts, and that the Boreal province here touched on the Lusitanian province (so to speak) of the Pleistocene period.

A widely spread mass of limestone gravel, probably not less than 100 to 150 feet thick, forms the gently swelling tract known as the Curragh of Kildare.

The Coal-measure hills of Castlecomer coalfield have the Limestone gravel on their flanks, and also isolated patches of it with blocks of limestone of a foot or more in diameter in hollows on the top of the

table land at heights of as much as 700 and even 1000 feet above the sea (see *Explanations of sheets* 128, 137, and 146 *of Geol. Sur. Ir.*)

Other spaces at lower levels are quite free from any Drift, and it is doubtful in these cases whether the Drift was deposited in local patches or whether it once formed a general covering to the country, and has since been in part removed by denudation.

Limestone gravel, often with large blocks which are picked out by the farmers and burnt for lime, is found high up on the northern flanks of all the hills of the south of Ireland, such as the Knockmealdon, the Galtees, the Slieve Bloom, the Keeper group, and the Slieve Bernagh, and Slieve Boughta hills. In some cases the blocks are very large, Mr. O'Kelly mentions one of 25 ft. × 15 ft. × 5 on the Coal-measures near Killenaule (*Explanation* 146). Mr. Wynne gives a sketch of one 21 ft. × 9 ft. × 7½ resting on Silurian slate, at a height of 890 feet, near Moneygall (*Explanation* 135.) Mr. Du Noyer (in *Explanation* 184) gives a sketch of that known as Cloghvorra, near Kenmare, which measures 26 ft. × 16 ft. × 15 ft., and rests upon Old Red Sandstone, but may be derived from the limestone in the valley below. Others are to be found in the valley under Caherconreagh, in the Dingle promontory.

In a recent examination of Glenbarrow, on the north flank of the Slieve Bloom mountains, with Mr. O'Kelly, I was much struck with the facts to be observed respecting the Drift. These hills are composed of Lower Silurian rocks covered by Old Red Sandstone, and they slope gently down from heights of about 1600 feet to the limestone plain that stretches as far as the horizon around them to the west and north, and is only terminated towards the east by the Coal-measure hills of the Castlecomer coalfield, distant about ten miles. All the valleys of the Slieve Bloom seem once to have been completely filled with the great Drift deposit, rising with a gentle slope from the plain up nearly to the heads of the valleys. The present rivers have excavated channels for themselves either through this Drift, or between it and the solid rock, leaving the gently sloping surface of the Drift often most distinctly marked along the flanks of the more abruptly rising hills on each side of the valleys.* In some cases the lower part of the drift is composed of the Limestone gravel, which is however very clayey, but contains both well rounded pebbles and subangular blocks of limestone in great abundance. Over this come beds of fine sand and gravel, very regu-

* This appearance is general in Ireland in all the mountain valleys, and may be seen very characteristically in Glenismaule and the adjacent valleys near Dublin. The steeper hills, as they descend into the valleys, are met by gently sloping plateaus of Drift, forming inclined planes from the heads of the valleys towards their mouths, these inclined planes seeming once to have stretched continuously across the valleys, but being now deeply trenched by the ravines at the bottom of which the present brooks run. They have no analogy with moraines, and in Glenismaule the drift contains fragments of sea-shells near the mouth of the valley.

larly stratified, derived apparently from the local rocks, with comparatively little limestone. In some places this local deposit (which may be partly of atmospheric origin perhaps) entirely conceals the Limestone Drift below, except where the brooks cut deeply down into it.

In other cases the lower part of the Drift is formed of the local rocks, and the Limestone Drift occurs over it. One long escarpment of Drift in Glenbarrow, where the river is at a height of about 800 feet above the sea, and three or four miles from the limestone plain, shewed cliffs of Drift 120 feet high, all regularly stratified, the upper fifty feet consisting of coarse Drift with limestone boulders, underneath which were beds about 20 feet thick, of very fine laminated sand, and below that coarse rubbly Drift of sand and fragments, with angular blocks of Old Red Sandstone three feet in diameter. The rock below the Drift was Old Red Sandstone, which seemed to have suffered considerable erosion and local decomposition before the Limestone Drift was brought into the valley. The escarpment of the Drift was a nearly vertical cliff, being continually undermined by the river, which seemed to have cut down along the sloping surface of the solid rock which formed the opposite side of the valley deeper and deeper into the Drift, and to be now working slowly to clear its old valley of this recent deposit. I saw limestone blocks both in the Drift and loose in the river bed up to heights of 1260 feet in this glen; and Mr. O'Kelly assured me that he found small pieces of limestone and fragments of black chert, such as is found only in the limestone, even on the tops of the hills, above the level of any other Drift.

The observed facts would agree well with the supposition that the whole country had been once covered with a thick deposit of Drift that sloped up on to the flanks of the hills to a much greater height than it had on the low ground, and to a still greater height, perhaps, in the valleys, which would catch a greater quantity of it, and then that as the country rose above the sea, much of this loose superficial deposit had been removed from the outside slopes of the hills, and a good deal carried away from the plains, especially from off the summits of the lesser outlying eminences that rise from that plain, while the part that had filled the bottoms of the valleys was chiefly left in them, and is only now in process of removal by the brooks that began to form as the ground rose again above the sea, and have ever since ran down these valleys.

That these deposits were formed under the sea, notwithstanding the absence of sea shells from the greater part of them, and especially their upper part, I cannot have the slightest doubt; since it is impossible to conceive how limestone pebbles and boulders can have been carried *up* into the hills for so many miles and for so many vertical feet except by water transport. These conclusions are quite in accordance with those

of Professor Ramsay in his paper on the Drift of North Wales, before quoted (*Quart. Jour. Geol. Soc.*, vol. viii.)

Boulders of the Leinster Granite.—The Leinster Granite, occupying the position already described at p. 310, sends off boulders in all directions except the north, but chiefly towards the south-east. In the Luggala Glen, running partly between the Granite and the adjacent rocks, great blocks of Granite are perched by hundreds on the rugged cliffs of Mica schist on the east side of the glen, or that facing the Granite, and are strewed over all the country, whether on the hill tops or in the valleys, between the Granite and the sea. The largest of these blocks that I ever measured was an angular block lying in a field a little below Annagolan Bridge, on the north side of the Vartry river, in the townland of Boleynass Upper. It measured 27 feet in length, about 15 in width, and rose 11 feet out of the ground. Its circumference was 82 feet. It rested on the Cambrian slates and grits, at a distance of about six miles from the nearest Granite *in situ*, and on ground having a height of 620 feet above the sea. Between this block and the Granite hills is the deep and rugged ravine of the Anamoe river, the high ridge that runs down from Douce mountain on the east of that ravine, and the wide flat of the Vartry valley below Roundwood. Many other cuboidal and angular blocks, measuring fifteen or twenty feet in the side, may be found on neighbouring hills, and the valleys are full of smaller rounded boulders. Blocks of Granite, with a diameter of three or four feet, rest on the Cambrian rocks at the top of Bray Head, at a distance of five miles from the nearest Granite *in situ*, and separated from it by several deep valleys (see fig. 108).

Boulders of the Galway Granite.—The Granite which occupies, according to Sir R. Griffith's map, so large a portion of ground on the north side of Galway Bay, is easily recognisable, inasmuch as it contains hornblende instead of mica, and is therefore a syenitic Granite, and has large crystals of pinkish feldspar, and is therefore porphyritic. Blocks of it may be found scattered over all the country to the south of the Bay, through Clare and Limerick and the adjacent counties, as far south as Mallow in the county Cork, a distance of about a hundred miles in a straight line. Many blocks of two or three feet in diameter may be found in the country about Nenagh, and on both flanks of the Slieve Bloom Hills, up to heights of 1000 feet above the sea. Mr. O'Kelly met with one at a height of more than 1000 feet about six miles N.W. of Mountrath, from which a large piece had been split by wedges, probably to make gate posts, the part which remained measuring 10 ft. + 5 ft. + 3 ft.

The Galway Granite boulders, indeed, are numerous as far as the northern slopes of the Galtee mountains, but do not seem to have gone beyond the high grounds which stretch from those hills towards the

west, nor, so far as I am aware, are they found in the neighbourhood of Killarney.—(See the heading "*Drift*" in the *Explanations* of the sheets of the Map of the *G. S. Ireland.*)

Mr. O'Kelly remarked to me that these Granite boulders were chiefly on the surface, and not buried in the Drift, an observation that seems to me correct, and one that will apply also to the boulders of the Leinster granite. Some blocks, however, are found buried in the Drift, but may have been subsequently dropped into it while it was still at the bottom of the sea.

The Limestone gravel of the centre of Ireland seems also to have been arrested by the east and west ranges of mountains and high land that stretch across the south of Ireland from Waterford to the coast of Kerry, as the Drift in the southern valleys among these high lands and in the lower lands to the south of them seems to be chiefly of local origin, though great mounds and local accumulations of it are to be found in some places.

Killarney Drift.—Perhaps the largest local accumulation of Drift in Ireland is that which, commencing at the foot of the hills near Mill Street in County Cork, completely conceals the Carboniferous limestone and all other rocks from sight for a distance of twenty miles up to the foot of Mangerton. This forms a great plateau of coarse rubbish, consisting entirely of rocks such as the hills to the south and west of it are composed of. It seems to be from 100 to 300 feet thick, and sweeps up on to the flanks of the hills to a height of 600 and 700 feet.

This Drift ends in a steep slope or escarpment a little south of the Lower lake of Killarney (See Mr. Du Noyer's sketch in *Explanation of Sheet* 173, *Maps of G. S. I.*), so as to allow of the reappearance of the limestone from beneath it, but sets on again below the lake, and buries all the rocks from view along the foot of the hills, across the mouth of the Gap of Dunloe, and thence down to Killorglin and Rossbeigh, another space of ten or twelve miles long by four or five in width.

The hills seem to have formed the shore of part of the old Glacial Sea, along which their waste was deposited in great abundance, little of it being carried off by the currents. During the subsequent elevation, the hollow of the Lower Lake, and the flat land immediately on its borders, was denuded of this Drift, probably by the action of the current, which would at one time set out of the valley of the Upper Lake.

The North of Ireland is just as much covered with Drift and with transported boulders as the south, and I believe that the same descriptions will, "mutatis mutandis," apply to the whole country. Sir R. Griffith has stated that the Granite blocks of the Ox range of mountains in Mayo and Sligo are carried some miles to the north as well as to the south. Blocks of Granite and other associated rocks are found scattered over the basaltic plateau of Antrim as well as elsewhere.

Glacier Smoothings and Groovings, and Moraines.—The rocks of many parts of Ireland, especially those of the south-west corner of it, exhibit in great perfection that rounding, and polishing which glaciers communicate to the rocks over which they glide. So perfectly indeed are all, even the hardest rocks, rounded and smoothed, that the very universality of the process prevents its striking an eye not instructed in the nature of the phenomenon. The summits of the highest mountains, as Mr. Du Noyer has remarked to me, bristle with rough peaks and crags, but their lower slopes are all smooth and rounded, and this smoothing is continued down even below the level of the sea. In many cases precipitous faces of hard rock have been *undercut* into broad grooves and mouldings, of several inches in depth and a foot or two in width, just as the precipices which glaciers now rub against are grooved. These are beautifully shewn, by the roadside, in the pass over Mount Gabriel, a few miles north of Skull, in county Cork, and were declared by Sir H. T. Dela Beche, when he visited the spot with me in 1851, to be as perfect as anything he ever saw in the Alps.

The surface of the rocks on the slopes and tops of the hills are traversed also by "glacial striæ," or scratches running in parallel lines on the surface of the hard rocks, deep enough for a thick pencil to lie in.

These marks are precisely such as have been described in Wales, in Scotland, and other parts of the British islands, as well as over northern Europe and America, and are now generally accepted as proofs of the former presence of glaciers.

The Drift in some of the mountain valleys, or at the mouths of those valleys, is sometimes arranged in semicircular or horse-shoe shaped ridges, which have been held to be the terminal moraines of these old glaciers. They may in some cases really be so, but in others I have had some doubts as to whether they were really a pile of blocks dropped at the end of a glacier, or one heaped up there by the action of the sea tides and currents washing in and out of the valley, from which, perhaps, block-laden shore ice floated occasionally, the ridge being subsequently modified by the river action when the valley became dry land.

It is, however, quite clear, that when our present mountains were covered by perpetual snow, and their valleys partly filled by glaciers, such of those glaciers as did not end in the sea must have had terminal moraines.

It is possible that at one time during the glacial period our lands may have been much more lofty than now, but it is quite beyond doubt that, at the time when the Limestone gravel of Ireland was spread over the country, and the Granite boulders scattered over it, the tops of the mountains only were above water, forming small islands. Icebergs and shore ice proceeding from those islands carried out to sea the blocks which were frozen into them or fell on to them during the

winter, and when they melted during the summer, they dropped those blocks promiscuously on the old sea bottom, very frequently on the submarine rocks and shoals which arrested the icebergs in their passage, and now form some of the hills of our present lands. These icebergs and icefloes would in some cases be drifted off from the islands towards the north, until they got within the sweep of the prevailing set of the currents, which, during this period, was certainly towards the south. They would, moreover, be more likely to melt away and drop their burdens while moving south than when going in a contrary direction.

It is remarkable, as shewn by the contour maps prepared formerly by the Ordnance Survey (a reduced copy of which will be found in Sir R. Kane's *Industrial Resources of Ireland*), that a depression of only 250 feet would completely alter the shape of what would then remain of Ireland, and one of 500 feet would convert it into two archipelagos of small islands with a broad sound between them stretching from Dublin Bay to Galway Bay. Any subsequent depression would not greatly alter these two small archipelagos, except by diminishing the number and size of the islands, until, when the depression reached 2000 feet below the present level, a few little islets only would be left, marking the position of the isolated groups of mountains now existing in the south and north of Ireland respectively.

It must be recollected that, during the submergence of the land, and during its subsequent re-elevation, the motion was most probably a slow and gradual one, and that every conceivable gradation of relative altitude must therefore have existed at one time or other between the present levels of the land and its greatest depression.

It must also be borne in mind that the position and arrangement of the superficial materials, as they now exist, received their last modifications from the sea during the last *elevation* of the land, and have been subsequently modified by subaerial action alone. The latter action has in many instances been greater than might at first be thought possible, for it must be recollected that the land, on its first elevation, would not be covered by soil or vegetation, and that the rain-fall may have been greater than now, when the climate was different.

The existence of glaciers on our mountain tops, and of icebergs carrying blocks over our submerged lower lands, as proved by the phenomena now briefly described, is in harmony with the fact of the existence of northern and Arctic shells in the fossiliferous parts of the drift, and also with the existence of the *woolly* Elephant and *woolly* Rhinoceros, and the Reindeer, and other animals which will be mentioned presently.

Denudation during the Pleistocene Period not great.—All the facts connected with the Drift, especially the marks of glacial action on the surface, prove that the actual erosion of rock, or amount of denudation,

that was caused during the Pleistocene period, was comparatively very small. The present surface of our lands, as it would be if the Drift materials were removed, was of course the surface on which they were deposited; that surface was formed, therefore, before their deposition, and the surface of the parts now uncovered by Drift is merely a continuation of that part of the surface which is so covered.

The sea or the ice of that period exerted some action, doubtless, in the way of erosion, just as ice and sea have exerted some action since, but there is no evidence to shew that much greater erosion or destruction of rock was caused during the Pleistocene period than has taken place since. What the Pleistocene sea and ice principally did, was to rearrange the looser materials which previous erosive action had prepared for them, or to remove in some places a little of the external skin of the previously existing surface. Any considerable amount of denudation requires a lapse of time infinitely greater than has gone by since the commencement of the Pleistocene period, however many millions of ages may be allowed to have passed since then.

Eskers.—There is a good deal of interest attached to the external form of some of the accumulations of Drift in Ireland. The deposit has evidently been in many places modified and shaped externally by the currents of the water, either at the time of its deposition or subsequently. The great bank of Drift near Killarney, and its removal round the Lower lake, is one instance of this. There are, however, other conspicuous instances in the south of Ireland where the general form of the adjacent high lands has evidently some connection with the present external form of the Drift deposits in the low lands about them. Huge mounds of Drift are often accumulated in a bight of the hills, especially when there is a valley leading through the hills at the head of the bight. This is the case with the Drift mounds in the Kilmastullagh valley between the Arra mountains and the extension of the Silvermines Hills towards O'Brien's Bridge; with the Drift mounds near Broadford in the north-west bight of the Slieve Bernagh range; and with the Drift mounds near Roscrea, to the west of the valley between the south end of the Slieve Bloom hills, and the north extension of the "Devil's bit range." The great mounds of Drift near the town of Tipperary and those of the Curragh of Kildare have probably also a relation to the adjacent high land.*

* I believe this observation might be extended much farther than Ireland. I was struck last summer in the Lake country with the great piles of Drift on the north side of the watershed of the pass between Ambleside and Keswick, called Dunmail Raise, and with the lesser but still conspicuous mounds about the watershed on the road from Ambleside to Coniston, and in other similar situations. In the summer of 1860 I was equally struck with the great Drift mounds so similar to those of Ireland, which are met with in Switzerland on the road from Horgen to Zug, immediately after passing the watershed. In all these cases the

These mounds probably received their form during their first accumulation, but in other cases the surface of the Drift seems to be one caused by subsequent erosion. In one conspicuous instance, two or three miles north of Parsonstown, which I visited in November 1861 with Mr. A. B. Wynne, a widely-spread expanse of deep, horizontally stratified Limestone gravel seems to have been so far acted on by subsequent denudation as to have now an abruptly undulating surface, consisting of small mounds, ridges, and valleys, running in various directions over a space several miles in length, and one or two in breadth. One of these ridges, however, and the most conspicuous of them, formed a long Esker (as such ridges are called in Ireland), or narrow gently undulating bank, some fifty feet above the surrounding flat country, and some miles in length.

These Eskers are very numerous in Ireland over all the low central plain. One is to be seen three or four miles to the west of Dublin, running from the banks of the Dodder past the old castle of Tymon by the Green Hills towards the valley of the Liffey. Others are marked on the Geological maps near Stradbally in the Queen's county, near Bagenalstown, near Maryborough, near Phillipstown, and in several other places. (See explanations of sheets 100, 101, 102, 111, 128, 144, 147, 154, 155, among those already published).

The general form of an Esker is that of a long bank with steep sides, rising to a height of from 20 to 70 feet above the neighbouring ground. It is sometimes not more than a few yards wide on the top, but at other times spreads into wider mounds, and sometimes sends out spurs or terminates in two or three undulating mounds. The broader parts of an Esker often have deep circular or oval hollows in them, 50 or 60 yards wide at top, and 30 or 40 feet deep, without any outlet. Eskers often spring insensibly from a slope at the foot of a hill, and stretch with a gently undulating line for several miles across the flat country.

The Maryborough Esker commences at the foot of the Coal-measure hills a little south of Maryborough, and runs off to the northward unbroken for seven miles to near Mount Mellick. It is then interrupted by a gap of a mile and a half, through which the little river Ownass flows, but sets on again in the same line for another mile and a half, beyond which it coalesces with some irregular gravel mounds. It stretches obliquely across the mouth of the wide open valley between the Coal-

accumulations occurred where there must once have been a straight between islands, and where, accordingly, the tidal and other currents would be likely to meet and oppose each other.

In this, as in many other cases, the officers of the Geological Survey, though they may find themselves on the traces of generalisations of great interest, must be content with indicating them to the researches of others whose time and movements may be at their own disposal.

measure hills and the Slieve Bloom mountains. It does not, however, touch the latter, but sweeps in a parallel line round their north-east corner.*

The Bagenalstown Esker commences in the limestone flat, but runs from that on to the Granite, ascending a gently sloping ridge which is 120 feet higher than the limestone plain, still preserving its form of a bank 40 feet high, until in about three miles it gradually spreads into low gravel mounds and becomes lost in the general mass of the drift which there covers the Granite.—(Explanation of sh. 147 and 157).

These Eskers are often opened for gravel pits, as may be seen at the Green Hills near Dublin, and the arrangement of their materials is very curious. Irregular beds of large blocks, or of small pebbles, or of the finest sand, are arranged one over the other, generally with a rude attempt at conforming to the external slopes of the ridge, but not preserving for any distance either their thickness or inclination. These irregular beds seem to have been formed by the piling action of two opposing currents, or to have been heaped up in the eddy at the margin of currents running in different directions.

Many of these ridges seem to have been similar to "harbour bars"† in their mode of formation, and to be directly related in this way to the valleys running into the neighbouring hills, which must, of course, have formed bays or harbours during some part of the last slow rising of the land above the sea. Others, however, especially those numerous ones that run in various directions all over the great central plain of Ireland, can only have been formed in the open sea by the action of different currents, as that sea became shallow in consequence of the elevation of its bed.

These Eskers of the plains are often associated with the bogs, either running in lines between two large bogs, or partially or entirely surrounding flat spaces, which seem to have been converted into bogs in consequence of the Eskers having at one time retarded, and perhaps still retarding in some places, the drainage of the country, the superfluous water soaking through the porous base of the Esker instead of making a regular brook or river channel for itself to run off by.

* The country people about Maryborough affirm that this Esker stretches all across Ireland. Mr. Wynne was told that an Esker, near Borrisokane, a long way to the west of the Slieve Bloom mountains, was part of that near Maryborough. These stories may be taken as evidence of the similarity of the Eskers at different places, and their frequent occurrence in the centre of Ireland. Some of them seem certainly to be 15 or 20 miles in length, if we allow for occasional gaps or interruptions.

† An excellent example of an old harbour bar may be seen at the Seven Churches in county Wicklow. All the ruins are on a bank of Drift stretching across the main valley, and formed partly of the detritus from that valley, but chiefly, perhaps, from the other steeper and narrower valley, which must at one time have emptied its drainage into the old harbour just about this point, and brought down the detritus, of which the tidal currents formed the bar.

The centre of Ireland between Dublin and Galway, and from Nenagh to the counties of Mayo and Sligo, is largely occupied by a succession of great bogs and Esker ridges, the rounded blocks in the latter being often of large size, and heaped up in the greatest confusion and abundance. This flat country looks as if it had been but lately lifted up out of the sea, still bearing the marks of the beating of the Atlantic waves, and the washing to and fro of its tides and currents.

Subsequent Elevation and widely-spread Plains.—It is probable then that the Eskers and other modifications in the external form of the Pleistocene deposits were produced during the rise of the old sea-bed into dry land. It is also probable that the result of that elevation was a widely-spread plain, something like what Northern Siberia now is, which perhaps connected the British Islands with the Continent; and that the English Channel, and the Irish and North Seas, have been formed by the erosive action of the Atlantic eating into the lower and softer parts of that plain. On this plain many lakes existed, which have been filled up with lacustrine deposits, containing the bones of such animals as the great Irish deer (Megaceros Hibernicus), and others.

Cave Deposits.—It was probably also at this time, that is, after the last elevation of the land, that the caves of the British Islands and the Continent were inhabited by wild beasts, such as the Cave Hyæna and Cave Bear, which have left their remains buried in the mud at the bottom of these caves, that mud having been covered and preserved by a deposit of stalagmite.

Raised Beaches, Low Level Gravels.—Besides the widely-spread Drift, containing recent shells, there are also to be found in many places more local deposits seeming to have been formed as beaches on the margin of the sea, but now lifted up beyond the reach of high water. The exact date of these deposits, or that of their elevation, with relation to the deposition or elevation of the widely-spread drift, is often a very difficult point to determine.

The Low Level Gravels are those deposits which have been formed at the bottom of our present valleys since the deposition of the Boulder Clay, many of their materials being derived, probably, from that boulder clay in the regions into which it spread, or from the high level gravels or other superficial deposits where the boulder clay was absent.

The bones of the Mammalia that inhabited the adjacent high grounds, and the shells, either land or fresh water, of existing Mollusca, are to be found in these lower gravels, many of which seem to have been formed in the rivers and estuaries, when the country was at a little lower level, or before the rivers had cut so deeply down into their present beds, and when they consequently flooded the adjacent grounds to a greater extent than now.

One fresh-water shell, which was called Cyrena trigonula, when first

found in the Crag, and Cyrena consobrina when found living in the Nile, and now is called Cyrena (or Corbicula) fluminalis, seems to have survived many mutations and alterations of surface. It is found in many of the fresh-water deposits above the Boulder Clay, as shewn by Mr. Prestwich lately in his paper on its occurrence with recent marine shells in beds of sand and drift over the boulder clay near Hull.—*Q. J. G. S.*, vol. xvii. p. 446).

Submarine Forests and Peat Bogs.—Around all the shores of Ireland there is frequently to be found evidence of a comparatively recent depression of the land having taken place, in the occurrence of undisturbed peat bogs beneath the sand of the sea, stretching below the level of the lowest spring tides. Turf has lately been found beneath the mud of Wexford harbour. At numerous points along the south and west coast of Ireland it is a common practice for the country people to go to the head of the sandy bogs, at dead low water of spring tides, and dig turf from underneath the sand, and it has been equally noted in similar situations along the western and northern coasts.

The stumps and roots of trees in the position of growth are found in this peat, clearly shewing that it grew on the dry land, and its very general, we might almost say universal, occurrence, round the coast, shews that no local position of sand hills or other barriers can account for the land having been dry, but that it formerly stood at a higher level, and is now beneath the sea in consequence of depression.

There are many points on the coast of England also, where similar facts are observable. I dug a stump of a tree full of living pholades out of the turf at the margin of dead low water of a spring tide between the mouth of the Dee and the Mersey in the summer of 1837. Old land surfaces have been found beneath the fens of Cambridge below the level of the sea.

It is therefore certain that since the elevation which lifted up the great glacial plain into dry land, there has been a subsequent depression, which has aided the sea in diminishing the size of our islands, and increasing the width of the "Narrow Seas;" and that this has occurred since the formation of peat bogs, which are exactly similar to the lower parts of the peat bogs in the interior of the country.

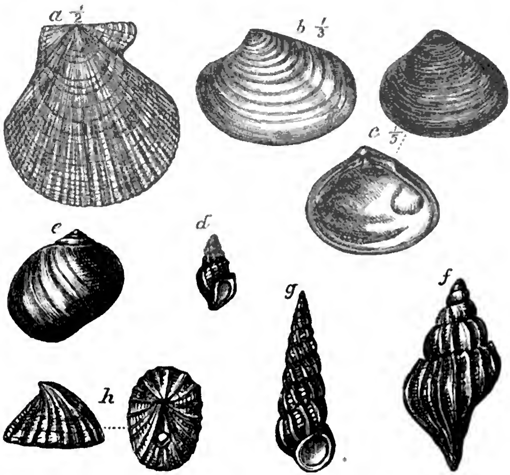
Characteristic Fossils of the Pleistocene Deposits.

Conchifera.

Astarte borealis, A.* and Crag . .	Ly. Man., fig. 110.
——— elliptica, N. C.	Foss. gr. 48, *b*.

* In this list A. stands for Arctic, B. for Boreal, C. for Celtic or the British seas, N. C. for North Celtic, or the seas of the coast of Scotland, etc.

Cardium edule (common cockle), and Crag	Wood, Crag. Moll.
Cyprina Islandica, B. and C., and Crag .	*Ibid.*
Cyrena fluminalis (also called C. consobrina, when living in the Nile, and C. trigonula when fossil in the Crag) . . .	Foss. gr. 48, *c.*
Leda rostrata, A. (called also Nucula oblonga)	Tab. View.
Mactra solida (all European seas and Crag)	Sow. M. C. 160.



Fossil Group No. 48.

Pleistocene Fossils.

a. Pecten Islandicus.
b. Astarte elliptica.
c. Cyrena fluminalis.
d. Fusus Fabricii.
e. Natica Greenlandica.
f. Fusus scalariformis.
g. Scalaria Greenlandica.
h. Cemoria Noachina.

Mya truncata, B. and C., and Crag . .	Tab. View.
Ostræa edulis (common oyster), and Crag.	
Panopæa Norvegica, and Crag	Tab. View.
Pecten Islandicus, A.	Foss. gr. 48, *a.*
Pholas crispata, B. and N. C.	
Saxicava rugosa (widely spread) . .	Tab. View.
Tellina Balthica (solidula) (all European seas).	

Gasteropoda.

Cemoria Noachina, A. and B. . .	Foss. gr. 48, *h*.
Fusus antiquus, B. and C., and Crag	Wood, Crag. Moll.
—— Bamffius, B. and U. C. . .	Tab. View.
—— Fabricii, A.	Foss. gr. 48, *d*.
—— Islandicus, A. B. and C.	
—— scalariformis, A.	Foss. gr. 48, *f*.
Littorina littorea (common periwinkle)	Wood, Crag. Moll.
Natica clausa	Ly. Man., fig. 114.
—— Greenlandica, A. and B. .	Foss. gr. 48, *e*.
Patella vulgata (common limpet), and Crag	Tab. View.
Purpura lapillus, A. B. and C., and Crag	Tab. View.
Scalaria Greenlandica, A. and B. .	Foss. gr. 48, *g*.
Turritella communis (European seas)	Tab. View.

Note.—On this part of the subject the student will find full information in Edward Forbes's paper on the "Geological relations of the existing Fauna and Flora of the British Isles," in *Mems. Geolog. Surv.*, vol. i., and also in his *European Seas*, completed by Mr Godwin Austen.

Mammalia.

Elephas antiquus.	
—— primigenius	Tab. V. and Ly. Man.
Rhinoceros tichorhinus . . .	Owen, Foss. Mam.
—— leptorhinus	Tab. V. and Ly. Man.
Hippopotamus	Owen, Foss. Mam.
Megaceros Hibernicus . . .	Tab. View.
Cervus tarandus (priscus), Reindeer .	Owen, Foss. Mam.
Bos antiquus.	
— primigenius	Owen, Foss. Mam.
Felis spelæa	*Ibid.*
Hyæna spelæa	Tab. V. and Ly. Man.
Ursus spelæus	Tab. V. and Ly. Man.

Northern Europe.—The description of the Drift and Erratic blocks of the British islands will generally serve also for those which spread over Northern Europe. The plains of Germany are strewed with fragments of the rocks of Scandinavia, some of them as big as cottages, that have evidently been carried by ice over the Baltic, and dropped as the ice islands melted away in the seas that then extended from the mountains of Norway over the low lands of Europe. This Northern Drift is limited by a singularly tortuous line that runs from the Tcheskaian Gulf (east of the White Sea), south towards the Ural Mountains, but is then deflected back, and undulates boldly through the centre of Russia, to the foot of the Carpathian Mountains, marking

probably the limit of the Pleistocene Sea, during the time when the blocks were being transported. Its farthest point south is about Cracow, latitude 50°, and it runs thence along the northern foot of the highlands of Bohemia and Saxony, and the Hartz mountains, to the plains of Holland about the Zuyder Zee, and thence probably across the south of England, up the valley of the Thames, to the mouth of the Severn, in the Bristol Channel.

The Alps and Switzerland.—The Alps, however, formed a local centre of Drift of their own, into the sea which probably then washed their foot, large blocks being sent on icebergs for some miles, both to the north and to the south. Blocks of rock from the different parts of the central Alps rest upon those points of the Jura which are opposite to the valleys issuing from them, each valley carrying blocks from the rocks near its source. Some geologists believe that these blocks were carried on dry land by the glaciers, which they suppose then to have extended across the middle lake district of Switzerland over the soft accumulations of the Molasse, and to have climbed the slopes of the Jura. The existing glaciers of Switzerland were certainly once far more extensive than they are now, as is shewn by the ice marks in the lower valley of Hasli for instance.

India.—From Dr. Hooker's Himalayan Journals, it appears that the glaciers of the Himalayan mountains were in like manner much more extensive formerly than they are now.

Loess and Lehm of the Rhine Valley.—These deposits consist of fine sand and loam, with occasional layers of gravel. They are found on the hills bordering the Rhine and its tributary valleys up to heights of more than 1200 feet near Basle, and on the summits and flanks of the hills down to the flat near Cologne.

The fossils in them consist chiefly of land and fresh-water shells of existing species, together with bones of the Mammoth and other land animals.

Lyell believes that, as the land rose from its depression beneath the glacial sea, the fresh-waters of the valley, having at first a very gentle fall, would spread more or less over the neighbouring lands as they just emerged from the sea, and afterwards, as the land rose, would be gradually and successively contracted to their present bed. Thus the fresh-water deposits might be found at various heights over all the country that had suffered depression, according to the various conditions of that surface during the subsequent elevation.

What is true for the Rhine valley will also, doubtless, apply with equal truth to many other districts.

North America.—For information as to the glacial phenomena of North America, I must refer the student to Dr. Bigsby's paper, "*On the Erratics of Canada,*" *Q. J. G. S.*, vol. vii. p. 215, and Professor Ramsay's

paper "*On Glacial Phenomena of Canada, etc.,*" *Q. J. G. S.*, vol. xv. p. 200; and Dr. Hector's paper "*On the Geology of the Country between Lake Superior and the Pacific Ocean,*" *Q. J. G. S.*, vol. xvii., and the publications of the Geological Survey of Canada under Sir W. Logan, and the various Geological Surveys of the United States.

Sicilian Beds.—In Sicily and other parts of the Mediterranean Basin there are recent tertiary deposits, which, from the great proportion of existing species they contain, belong seemingly to the Pleistocene Period.

Lyell describes those of Sicily as rising in some places to a height of 3000 feet above the sea, and covering nearly half the island. They consist of the Girgenti limestone above, having an aggregate thickness of 700 or 800 feet, beneath which is a sandstone and conglomerate passing down into clay and blue marl. The limestones are in some places like the Calcaire grossier of Paris, but in others are nearly as compact as marble. South of Catania these beds are interstratified with lava and ashes, and traversed by dykes, and form an aggregate not less than 2000 feet thick. In one place a bed of oysters (our common edible species), twenty feet thick, rests on a bed of basaltic lava, and is covered by other lavas and ashes. In another spot a bed of a common Mediterranean coral (Caryophyllia cæspitosa), all the individual masses standing erect as they grew, and about a foot and a half thick, may be traced for some hundreds of yards on each side of a valley. The fossils contained in these beds are chiefly of species now living in the Mediterranean.—*(Lyell's Manual.)*

These formations were either wholly or in part in course of production in the bed of the Mediterranean during the time when our Pleistocene Drifts were being formed.

CHAPTER XXXIX.

PLEIOCENE AND PLEISTOCENE.

LIFE OF THE PERIODS.

THE most striking fact in the forms of life during these later Tertiary periods is the general one already alluded to, namely, the gradual and successive appearance of the species which now inhabit the globe.

Among the lower ranks of animals, as, for instance, the Mollusca, more than one-half of the species found fossil in the earlier Pleiocene beds are the same as those which now exist, and of the remainder, which are now extinct, each species as it died out had its place taken by another form which still remains a living species, these being found in greater proportionate numbers in the later and later deposits.

In the higher orders of life, however, as among the Mammalia for instance, we do not find the same specific identity in the earlier Pleiocene deposits as among the Mollusca. It has been remarked before, that the duration of species is longer among the lower ranks of life than the upper. While so many, then, of the species of Mollusca that lived in the earlier part of the Pleiocene period still survive upon the globe, the species of the Mammalia that then lived have become extinct; but their places have been taken by other closely allied species, which can, for the most part, be included in the same genera with them. Those genera almost all still exist upon the earth, their existing species gradually making their appearance in the newer deposits of the subsequent periods.

Sir C. Lyell, in the supplement already quoted (which I hope before the publication of these pages to see incorporated in a new edition of his *Manual*) gives the following generalisation as to the marine testacea of the three Crag deposits, quoting Mr. Searles Wood's monograph in the publication of the Palæontological Society, and acknowledging the assistance of Mr. Woodward.

The number of species of marine testacea in the Coralline, Red and Norwich Crags, is 442—of which the first has 327 and the second 225, the number of species common to the two being 116. The species

in the Norwich Crag are 81, of which 4 are found also in the Coralline and 33 in the Red Crags.

The percentage of recent species is in the Coralline Crag, 51, their total number being 168, of which 27 are not found living in the British but in more southern seas, while 2 are only found in northern seas. The percentage in the Red Crag is 57, the total number of recent species being 130, of which 16 are found in southern and 8 in northern seas. The percentage in the Norwich Crag is 85, the total number being 69, of which 12 only do not live in British but in northern seas, none of them being inhabitants of southern seas only.

These facts afford an interesting and instructive example of change at once in the forms of life and the climate of the region. They shew the influence of the gradual refrigeration of the climate during the deposition of these Crag deposits, which reached its maximum a little later, during the deposition of the Northern Drift or Glacial deposits.

Edward Forbes shewed that species of Mollusca which inhabited the British seas during the Pleiocene Period, retreated to the south before the cold climate which spread gradually from the north in the Pleistocene Period, and became then inhabitants of the Mediterranean and adjacent parts of the Atlantic. These shells are found fossil in the Pleistocene deposits of those regions, but many of them are not now found living there, having returned to our seas as the cold influences were confined more and more to the north, and the ocean currents from the south modified the severity of the climate. Some of these species, however, still linger in certain localities in the south, a remarkable instance being the discovery by Mr. MacAndrew of the common Red Crag shell, Fusus contrarius, still living in Vigo Bay, a deep fiord on the coast of Spain, together with a complete colony of other Celtic species within the Lusitanian province.—(Ed. Forbes on *Nat. Hist., European Seas*, p. 109).

Forbes's Celtic province seems to have come into existence between the Boreal and Lusitanian provinces as a consequence of these changes of climate, an opening having been made between the two which has been subsequently occupied by that peculiar assemblage of species to which he gave the name of Celtic.

Among the Mammalia Dr. Falconer has clearly distinguished two assemblages in Europe and the British Islands, one belonging to the Pleiocene and the other to the Pleistocene Period of time; or as regards some which were contemporaneous during the latter period, some being confined to the north and others to the south of Europe.

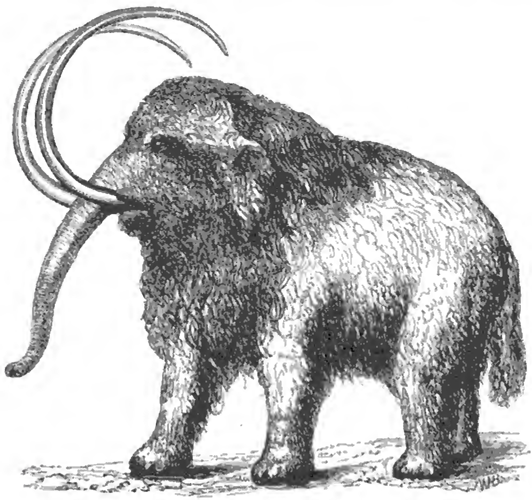
The Pleiocene or Southern Mammals comprise *Mastodon* (*Tetralophodon*) *Arvernensis*; *Elephas* (*Loxodon*) *meridionalis* and *priscus*; and *El.* (*Euelephas*) *antiquus*;* *Rhinoceros leptorhinus* and another;

* Prestwich says that Euel. antiquus and primigenius were not only contemporaneous, but even co-inhabitants of the same district for at least part of the time.

Tapirus arvernensis; Hippopotamus major; Equus plicidens; Felis pardinensis; Ursus arvernensis; and a species of *Canis*, to which, according to Owen, may be added a species of *Machairodus*.

The Pleistocene or northern assemblage contains *Elephas* (*Euelephas*) *primigenius; Rhinoceros tichorhinus; Megaceros Hibernicus; Ursus Spelæus; Hyæna spelæa;* to which may be added, according to Owen, *Bubulus moschatus*, still living in the Arctic regions of North America, and several other species of gigantic *Bovidæ*, as well as wolves, foxes, badgers, otters, wolverines, martin cats, weasels, beavers, and other animals in the cave breccias and other deposits, some of existing, some perhaps of extinct species.

It may perhaps be doubtful how many of these species were contemporaneous inhabitants of separate provinces during the earlier period, and shifted their area in consequence of the change of climate during the later period, but it is certain that the Pleistocene succeeded



Fossil Fig. No. 49.
Pleistocene.—Euelephas primigenius.

the Pleiocene fauna in our islands and central Europe, and perhaps long survived them, either here or in more northern regions, after our climate had become unsuitable to them.

Of the Mammoth (El. primigenius) not only are immense numbers of teeth and tusks found in Siberia, and complete beds of them in Escholtz Bay on the north coast of America, but the whole carcass has been recovered from a frozen cliff in Siberia, and found to be covered with long coarse hair, forming a shaggy main about the neck, underneath which was a woolly coat, evidently a defence against the severity of a cold climate. Its tusks are largely exported from Siberia to be used as ivory, and some found in England have been thus used. They were longer and more incurved than those of either of the existing elephants, some of the tusks measuring ten feet in length, while the transverse plates of the teeth were closer and narrower than the Asiatic elephant, and very different therefore from the African (Loxodon), in which the plates of enamel form lozenges on the upper surface.

The figure forming No. 49 of the Fossil Groups will give an idea of the probable appearance of the mammoth when living, an idea taken by Mr. Baily from Mr. Waterhouse Hawkins's Diagrams of Fossil animals.

At Escholtz Bay the cliffs are said to be either ice or coated with ice, and on the top of them, embedded in, and partly covered by, boggy and sandy soil, are numberless bones that have lost but little of their animal matter, hair being dug up with them, and the whole island having a charnel-house smell. The bones were those of *Elephas primigenius*, *Equus fossils*, *Cervus alces* (moose deer), and *C. Tarandus* (or fossil reindeer), *Ovibos* (fossil musk ox), *Ovibos maximus* (a musk ox of greater size than any living one), *Bison latifrons* (Arctic fossil Bison), *Bison crassicornis* (heavy horned bison), and other bovine animals.—(Richardson's *Polar Voyages*, p. 296.)

A whole carcass of the *Rhinoceros tichorhinus* has been in like manner dug out of the frozen soil of Siberia, and is described by Pallas as covered by a woolly coat.

No remains of these woolly animals have been found south of the Alps, nor anywhere in any other than Pleistocene deposits.—(*Falconer.*)

The Megaceros Hibernicus was not an Elk, as it is often called, but a true Deer, intermediate between the fallow-deer and the rein-deer—(*Owen.*) It inhabited the same frozen plains with the Mammoth and the woolly Rhinoceros, and with them was the prey of the gigantic Cave Bear and the Cave Hyæna, and other carnivora of the period.*

* The great antlers of the Megaceros Hibernicus, with their broad palms, are sometimes spoken of as likely to prevent its travelling through woods. The animal is usually set up, and drawn with its horns erect and pointing forward, but if the neck be curved and the nose of the animal thrown up, in the attitude in which deer gallop through woods, it will be seen that the broad palms of the antlers will fall back over his flanks, forming an admirable protection from stumps and old jagged branches, such as convert some parts of northern stunted forests into an almost impenetrable thicket. The broad palms of the horns would thus facilitate the animal's passage as he dashed through the old forest, while their tynes would all point backwards.

The remains of the gigantic Irish Deer or Big Horn are found as far south as the foot of the Pyrenees, and abundantly in some parts of Austria, although they are most numerous in Ireland, probably because lakes were more numerous there, in the clay of which, and in the bottom of the peat bogs that eventually spread over them, the remains were better preserved than elsewhere.*

Not only was the Irish Big Horn an inhabitant of Europe, but some of the other animals which inhabited Europe during the Pleistocene period spread into that part of it which now forms Ireland. This is certainly true for the Mammoth, the Rein-deer, and the Cave Bear, although the remains of these have not been found so abundantly in Ireland as in England and many parts of the Continent.

The discovery of the skeleton of a Mammoth (the teeth only being preserved) in the north of Ireland, is recorded in the *Philosophical Transactions*, in a letter from Mr. Francis Nevil to the Bishop of Clogher, dated July 29th 1715. The bones and teeth were found four feet below the surface in sinking the foundations for a mill at Maghery, eight miles from Belturbet, and about thirty yards from the brook which divides the counties of Cavan and Monaghan.

In March 1859 the bones and teeth of the Mammoth were found in a cavity opened in a limestone quarry close to the town of Dungarvan, together with some bones of the Cave Bear, the Brown or Fen Bear, the Rein-deer, a species of Horse of a size intermediate between the common horse and the Zebra, and the bones of a Hare and a Fox (Dr. Carte's paper

* In a discussion at the meeting of the Geological Society, Dublin, on 11th December 1861, several instances were mentioned of the bones of the Megaceros being found in peat bog, where, however, they seemed to be generally more decayed than when found in clay. Professor Haughton mentioned the discovery of a perfect skeleton in clay not more than a foot and a half from the surface in county Carlow, and the Rev. Mr. Brown stated that he was present at the disinterring of a specimen from a sand bed in an Esker ridge between Ballinasloe and Ahascreagh at a depth of fifteen feet from the surface, the bones being greatly decomposed.

A very learned paper on the Natural History of the animal by Dr. Scouler will be found in the first volume of the Journal of the Dublin Geological Society, in which he discusses the mention of large deer by Pausanias, by Julius Capitolinus, by Oppian, and by Pliny, and also the mention of the "*Schelch*" along with other animals in the Niebelungen lied; and enters fully into the subject of the possible identity of some of these animals with the Megaceros Hibernicus, and also examines the evidence then known as to the association of the bones with human implements. He also mentions the finding of a skeleton in gravel near Enniskerry, the bones being quite rotten.

The student will recollect that the state in which a fossil is found depends on the material in which it has been deposited, and not on the time it has lain there. Dr. Buckland had soup made from some of the bones of extinct animals found in the clay of a cave beneath a covering of stalagmite. Wood and shells, scarcely at all altered, are found in far older deposits than those of the Pleistocene period. It appears then that the bones of the Irish deer have been found, 1st, In Drift sand and gravels; 2d, In lacustrine deposits over the Drift; and, 3d, In the peat over the lacustrine deposits; their remains being best preserved in the second and worst in the first case.

in *Journal of Royal Dublin Society*, No. xv.) The bones were said to have been in great abundance when first found, being covered by broken fragments of limestone, which Dr. Carte supposes to have been the ruins of the roof of a cave.

The horns of the Rein-deer have been found in other localities, with those of the Megaceros, as recorded by Professor Oldham (in vol. iii. of the *Jour. of the Geol. Soc. Dub.*), where he describes a cutting through a bog at Kiltiernan, a few miles south of Dublin. He states, that in a layer of about two feet of mud and vegetable compost, covered by two feet of sand, and that again by four feet of bog, the heads and antlers of thirty Elks (Megaceros) were found, together with two heads of Rein-deer with perfect horns.*

Rein-deer horns are also said to have been found in Lough Gur, county Limerick ; and the skulls of Bears (supposed to be the black bear of Europe), some feet beneath the surface, in bogs in the counties of Kildare and Westmeath, and also in the county of Clare (*Explanation of sheet* 133 *of maps of Geol. Surv. Ireland*).

Buckland shewed long ago, in his *Reliquiæ Diluvianæ* (of which he afterwards acknowledged that the latter part of the title originated in mistake), that the old Bears and Hyænas of England and Germany inhabited for a long time the caves, in which their remains are most abundantly found, as their dens, and dragged into them for their food the other animals, or pieces of them, of which the remains are also found there. In the dens of these old extinct Hyænas of the British islands the bones of the other animals are found broken and gnawed as Hyænas now break and gnaw bones, and even the smoothed rocks, which were the old rubbing places of the animals, and their fossil dung (*coprolites*), have been preserved.

The newer Tertiary Fauna of America, Australia, etc.—We have already seen that during the Pleistocene period, as well as at present, the northern regions of Europe, Asia, and America, formed one zoological province. It appears that the Mammoth (*El. primigenius*) ranged quite as far south in America as it did in Europe at one time, and indeed much farther south—(*Sir C. Lyell's Travels in N. America*, vol. ii. p. 58)—if the identification of its remains by the American geologists be a correct one, and there be no other species there corresponding to the *El. antiquus* or *priscus* of Europe. The Mastodon is said by Sir J. Richardson never to have gone north of the Saskatchewan River, about latitude 51°.—(*Polar Voyages*, p. 296.) Some of the remains of Mastodon, at Big Bone Lick, Kentucky, were comparatively of recent date, since a half digested vegetable mass was found within the ribs of one skeleton.—(*Lyell.*)

* I believe these horns were more like those of the Carabou (*Cerf bœuf*), or Reindeer of North America, than those of the Lapland Reindeer.

In the southern part of North America the remains of animals called Mastodon giganteus and El. primigenius, and an animal intermediate between Lophiodon and Toxodon, and called Harlanus Americanus, a fossil horse, and others—(*Lyell, Q. J. G. S.*, vol. ii. p. 406)—are found together with those of Megatherium and Mylodon, thus leading us to the remarkable Pleiocene and Pleistocene fossil Mammalia of South America.

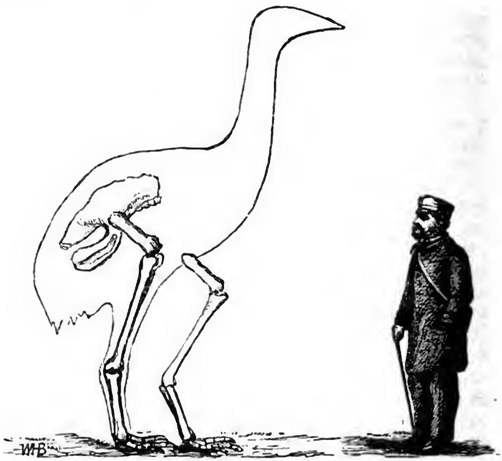
This South American fossil fauna includes progenitors, many of them gigantic ones, of the peculiar existing fauna of South America. The leaf-eating sloths of the present day, that inhabit trees, were preceded by gigantic sloth-like animals, that tore trees down, as the Mylodon, which was 11 feet long; the Megatherium, 18 feet long; the Megalonyx and Scelidotherium. The little existing Armadillos were anticipated by the Glyptodon, whose curved back, with its tesselated coat of mail, measures 7 feet across and 5 feet long; and the whole animal, from the snout to the end of its loricated tail, must have measured 9 feet. The Llamas were prefigured by an extinct genus called Macrauchenia, the Opossums by extinct species of Didelphys, the Platyrhine Monkeys by extinct species of that group of the Quadrumana, the Tapirs by species of Tapir, and the Peccaries by five extinct species of Dicotyles. There were also one, if not two, Mastodons, an extinct species of Horse (of which no living representative existed in America when first discovered by the Spaniards), and extinct species of Carnivora (*Felis*, *Canis*, etc.), and other animals. MM. Lund and Claussen are said to have brought from the Cave and other recent deposits of Brazil, no fewer than 101 species belonging to 50 genera of animals.—(*D'Archiac, Hd. p. de la G.*, vol. ii. p. 383)—and Charles Darwin added to the list (see his *Naturalist's Voyage, and Geology of S. America*, etc).

Australia.—Passing over to Australia, which now forms such a peculiar zoological province, we find in the caves and the recent freshwater deposits of that country, the remains of many extinct animals, having the same general type of structure with those that now live there. Gigantic Kangaroos (*Macropus Atlas, and Titan*), rivalling a horse in size, formerly roamed over the plains; a Wombat (*Phascolomys gigas*), as large as a Tapir, and an animal (*Diprotodon*) intermediate between a Wombat and a Kangaroo, also existed, the skull of which (now in the British Museum) is 3 feet in length, and another (*Nototherium*) somewhat smaller, and between a Kangaroo and a Koala (*Phascolarctos*). These animals were preyed upon by carnivorous marsupials of corresponding size; the *Thylacoleo* having been as large as a Lion, and other lesser ones probably existing, of less size, but with as much ferocity and voracity, perhaps, as are possessed by the living carnivorous marsupials now restricted to Tasmania, and known as the native Tiger

(*Thylacinus cynocephalus*), and the native Devil (*Dasyurus* or *Sarcophilus ursinus*).—*Owen's Palæontology.*

Professor Owen has also described a gigantic land lizard (perhaps 20 feet long) from these Australian Pleistocene deposits, under the name of *Megalania prisca*—(*Lin. Transactions*, 1858)—and states that it is allied to the present Australian Monitors and Lace Lizards.

In New Zealand we find the fossil remains of a gigantic wingless bird (*Dinornis*) allied to the small wingless bird (*Apteryx*), which still lives in that country ; another extinct ally of it being called *Palapteryx.* Of the Dinornis, Professor Owen believes that there have been eight or nine species of various sizes, from 3 feet to 10 feet in height. He believes that he has good evidence that at least one species, *D. elephantopus,* so named from its toe bones rivalling those of the elephant, was exterminated by the natives ; its bones having been found with every appearance of having been cooked.



Fossil Fig. No: 50.
New Zealand Pleistocene Fossils.
Dinornis giganteus.

In the Island of Madagascar, gigantic fossil eggs, thirteen or fourteen inches long, have been found, and also, I believe, some bones, and attributed to a large extinct bird, to which the name of *Æpyornis* has

been given. The Mauritius was inhabited by the Dodo (*Didus ineptus*), which was exterminated by the Dutch ; the islands of Bourbon and Rodriguez by the Solitaire (*Pezophaps*) ; and the little islands called Phillip and Norfolk Island, by large and beautiful parrots, which are also now extinct.

The Cape Barren goose of Bass's Straits, and the Black Swan of Australia, are destined to share the same fate, if the former has not already undergone it.

Neither is this dying out and extinction of species confined to the more remote or more newly discovered parts of the world, for if we return to the northern hemisphere and the Atlantic, we hear that the Great Auk (*Alca impenis*), if it do still survive on an islet on the coast of Iceland, will soon disappear, together probably with the last of the Pleistocene mammals that yet linger on the earth, namely the Musk Ox (*Ovibos moschatus*).

The local extinction of species, too, is remarkable in the total disappearance of the beaver and the wolf from England since the commencement of the historic period ; and the still more recent extermination of the capercailzie in Scotland, the bustard in England, and the wolf in Ireland, the last having been destroyed in Kerry so recently as the year 1710. The raths, or so called Danish camps, so numerous in Ireland, were, I believe, chiefly old cattle folds to protect the cattle at night from the wolves.—(Scouler *on Animals which have disappeared, etc., J. D. G. S.*, vol. i.)

Flint Implements in the Drift.—The mention of animals that have certainly been exterminated by man during historic times leads us naturally to the investigation of the question, how far the human species may have existed contemporaneously with some of those which have died out long before the times of either history or tradition, and how far man may have aided in their extermination.

For many years statements had been made as to the occurrence of human remains in caves and other places associated with the remains of extinct animals ; and also that skeletons of the Irish deer (*Meg. Hib.*) in Ireland, and of the Mastodon in America, had been found bearing the marks of wounds inflicted by human weapons.

There was, however, too much doubt about most of these cases for geologists to accept them as conclusive evidence in favour of the contemporaneity of a race of men with the older extinct animals.* Man

* The human skulls and bones described by Dr. Schmerling of Liege, in 1833, as found mingled with bones of many extinct animals, in a cave 200 feet above the Meuse, and as being in the same state as to fracture, colour, and condition, with the other bones, was justly considered a strong case in favour of the human and animal bones having been deposited contemporaneously by natural causes. The flint implements found by the Rev. Mr. M'Enery, Roman Catholic clergyman of Torquay (whose name all geologists were familiar with thirty years ago), in the cave called Kent's Hole, seems to have been another

digs, and may therefore have dug up fossil bones or buried those of his own race ; if holes in bones were really the result of wounds received during life, they may have been made by horned animals in fight, or by hard stakes while the living animals were penetrating thickets, or by other accidents. The human skeleton found fossil in the Island of Guadaloupe, and now preserved in the British Museum, is enclosed in a coral rock that may be of quite recent origin, since similar rock is formed now in the banks on coral reefs, or wherever calcareous grains are heaped upon coasts.

Discoveries have, however, been made within the last few years, which have brought the results of human workmanship within the scope of the same kind of evidence as that on which the geologist relies in all his other deductions, and which clearly proves the workmen to have been contemporaneous with the Mammoth and other extinct animals, and that they lived at a time when the physical geography of Northern France and Southern England at least was rather different from what it is now.

These discoveries are excellently described by Mr. Prestwich in the *Philosophical Transactions*, 1860, part ii., and Mr. J. Evans, in the *Archæologia*, vol. xxxviii., from which papers the following account is abstracted:—In 1841 M. Boucher de Perthes of Abbeville found the first flint implement in the drift of that neighbourhood, and published an account of his discoveries in 1847 and 1857 ; but it was not till 1859 that his work attracted the notice of geologists in general ; and the French localities were visited by Messrs. Prestwich and Evans, from whose reports they were afterwards examined by Sir C. Lyell and by MM. Desnoyers and Hebert, and other most competent and trustworthy observers.

The river Somme now, on approaching the sea, winds through a valley about a mile in width, the bottom of that valley having alluvial flats of silt and peat ; and the Chalk hills on each side of it rising gently up to heights of 200 to 400 feet above the sea, hills of 500 or 600 being only met with in the interior of the country. Abbeville and Amiens are both on this river, the first at fourteen, and the latter at forty-one miles from the sea, the mean level of the river being 60 feet at Amiens and 18 feet at Abbeville above the mean level of the tide at St. Valery at the mouth of the river. The Chalk hills are covered here and there with Drift sands and gravels, both on the higher grounds and on the slopes, down to the river valley, where the Drift passes under the silt and peat of the alluvial flats. This Drift is, in some places, 20 or

good case in proof. Dr. Falconer has lately found implements associated with bones of extinct animals in a cave near Palermo in Sicily. MM. Lund and Claussen, in like manner, found human remains associated with those of extinct animals in the caves of Brazil, under circumstances which satisfied them of their contemporaneous existence.

30 feet thick, resting on an uneven eroded surface of Chalk, and consists of sands and gravels, which lie often in regular layers over considerable areas, but, like all such deposits, are variable in the thickness and constitution of their beds, when places a mile or two apart are compared with each other.

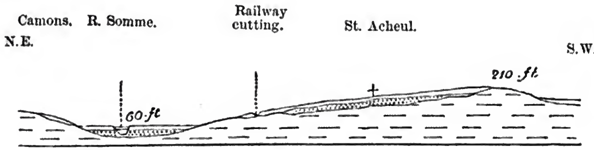


Fig. 123.

Section across Valley of Somme, near Amiens, reduced from Mr. Prestwich's section in the Phil. Trans.—Horizontal distance about 2 miles.

The lower part of this section is in chalk, represented by the horizontal strokes. The dotted portion represents the "drift," in which the flint implements are found associated with the remains of extinct mammalia, and with recent land and fresh-water shells, and occasionally some marine shells. The undotted beds above that, and on the slope of the chalk at Camons, and in the valley south-west of the hill marked 210 feet, are the brick earth and angular flint gravel. The upper undotted part on the flats of the Somme is silt and peat.

Marine shells are found in the Drift at some places, but at others land and fresh-water shells, of the same species for the most part as now inhabit the country, are found much more abundantly; teeth and tusks of the Mammoth, remains of the woolly Rhinoceros, and other extinct animals, are also found, and also a number of flints that have obviously been worked into parts of weapons or implements by the hands of man.

The flint implements and extinct animal remains are found chiefly in the lower parts of the Drift, often under more than 20 feet of undisturbed stratified sand and gravel, and evidently deposited in the water in which the Drift was deposited. They occur both near Abbeville and Amiens, at various heights, up to 90 feet, or thereabouts, above the river, often beneath ground which is the highest in the immediate neighbourhood, having gentle slopes from it in all directions. It is therefore impossible with the present outline of the country, and the present depth of the river valley, and relative levels of land and sea, that any fresh-water lake or river could have existed over the spots, and yet the sands and gravels have evidently been deposited beneath fresh water.

The following is a section of one of the gravel pits at St. Acheul near Amiens, where the general level of the ground is 149 feet above the sea, and 89* feet above the Somme. This ground slopes gently

* These are measurements accurately levelled by civil engineers.

to the N.E. for about a quarter of a mile as far as the railway cutting, and then more steeply to the flats of the river. To the south of St. Acheul it is not commanded by any higher ground, since there is a hollow between it and the foot of the hills to the southward.—(See fig. 123.)

	Ft.	In.
4. Surface soil	0	8
3. Brown loam in four beds, some of them slightly calcareous, others not so; a few naturally formed fragments of flint in some places; no organic remains or flint implements. This is the Brick earth	12	2
2. White siliceous sand and marl, with a few large subangular flints or blocks of sandstone, etc.—(*Land and fresh-water shells common; some Mammalian remains; flint implements*)	4	10
1. Coarse subangular flint gravel in a base of white siliceous sand, with whole and broken flints, pieces of Tertiary sandstone, etc., and Tertiary and Chalk rolled fossils, subordinate seams of sand sometimes level sometimes contorted, *Mammalian* remains, and *flint implements* dispersed throughout, but chiefly in the lower parts. *Shells*, mostly in fragments (*Helix, Limnea, Pisidium, Pupa*) in some of the sand seams	5	0
	22	8

The flint implements are found in some pits in considerable abundance, in others rarely, while in others they have never been found.

Mr. Prestwich believes these fresh-water deposits to be of the same age and character as the Loess and Lehm of the Rhine valley.

Similar flint implements have also been found near the village of Hoxne in Suffolk in some old brick pits. They were described by Mr. J. Frere, in a letter read before the Society of Antiquaries in 1797.—(See papers by *Prestwich and Evans* already quoted.)—Here they were found in clay containing fresh-water shells, and having some layers of flint gravel, the whole forming a lacustrine deposit in a hollow of the Boulder Clay which caps, or rather indeed forms the bulk of, all the hills around. This fresh-water deposit reaches within 6 or 8 feet of the summit of the hill on the slope of which it rests, at a height of 42 feet above the adjacent brook, 53 above the neighbouring river Waveney, and 112 above the sea. No ground more than a few feet higher exists for some miles around, and its position is such that "no existing drainage, nor any possible with this configuration of the surface, could have formed these clay and gravel beds at the relative level they now occupy."—

(Prestwich.)—The shells prove them to have been formed in a small lake or mere.

In May 1861, Mr. Prestwich read to the Geological Society of London a paper giving accounts of more recent discoveries of flint implements, with remains of extinct animals, near Bury St. Edmunds in Suffolk, near Herne Bay, and at Swale Cliff near Whitstable in Kent, near Bedford, and in Surrey and Hertfordshire, and calls attention to many other places at which they will probably be found when searched for.

Nobody could see a tray full of these flint implements, such as the collection of Sir C. Lyell and others, and retain a remnant of a doubt for an instant, that they had been fashioned by human hands. Some of them are like rude arrow or spear heads, while others seem as if intended for digging or grubbing up roots, being chipped to a strong rather curved point at one end, while the natural undulating surface of the flint is retained at the other, the flint having been apparently chosen on account of its natural indentations at that end fitting to the shape of the hand, and giving a good grasp to the fingers. The unchipped parts have the natural white coating which is commonly seen on weathered flints, while the chipped parts have the dark colour of the interior.

There can then be no longer any doubt that man not only existed on the earth generally, but even inhabited these countries, before the extinction of the following animals, which were then also inhabitants of the same region :—Elephas primigenius and antiquus, Rhinoceros tichorhinus, Hippopotamus, Equus fossilis, Cervus somonensis, Cervus tarandus priscus, Bos primigenius, Ursus spelæus, Hyæna spelæa, Felis spelæa ; and there can be little hesitation in admitting that Megaceros Hibernicus and others were most probably also in existence then. What race of men it was that had to defend themselves with rude flint weapons against the great bears, lions, and hyænas, and preyed with them on the old reindeer and other cervine and bovine or pachydermatous and proboscidean animals, and how many thousand years have elapsed since then, we are left to conjecture.

Any one who has read carefully the preceding pages can judge for himself as to the time requisite for the animals to have become extinct, and for the alteration in the levels and the minor features of the surface of the ground to have been produced.

The climate may have then been more excessive than now, but not perhaps more so than that of Newfoundland at the present day, which is in the same latitude as the northern part of France, and is still inhabited by reindeer and bears, and even invaded occasionally by the Polar bear landing from an ice floe, and which a century ago was inhabited by a race of Red Indians, who lived chiefly on the reindeer, and the last of whom have either perished or fled to the Labrador within the last thirty years.

CHAPTER XL.

THE RECENT PERIOD.

HAVING brought down our geological history to the recent period characterised by the existence of man upon the earth, we might naturally be called upon to continue it even to the present day, and to give an account of the geological changes that had taken place during the lapse of human history, and of those which were now in progress around us. If this were done fully, it could be shewn that the series of operations had been a perfectly continuous and equable one, even although our history of them might be incomplete. Whatever may have been the moral significance of the appearance of man upon the globe, it has, in a natural history point of view, been but the introduction of one more animal, superior to the rest in intelligence and therefore in power. We cannot find any geological evidence of any interruption in what is commonly called the "course of nature," of any alteration in the physical laws, nor any traces of a general catastrophe or cataclysm or disturbance of any kind, occurring either just previous to, simultaneously with, or subsequently to, the introduction of man upon the globe.

It is impossible to apply a literal interpretation to the account of the Noachian deluge given in the Bible, unless we are allowed to assume that it was a perfectly supernatural event, during which all the ordinary natural laws were completely suspended. Water enough to cover the mountains of the earth must have been miraculously added to, and miraculously removed from, the globe, without leaving any trace of its presence.

Geology by itself shews us that the mechanical erosion of our present dry lands, either by the waters of the ocean or those of the atmosphere, has been going on uninterruptedly from a vast indefinite period to the present day. The elevation and depression of the surface of the solid crust of the globe above or below the surface of the ocean, seems equally to have acted from the earliest geological periods, just as it is now acting in the nineteenth century, and even if it could be proved that its former intensity of action must have been greater than now, we can shew no proof of any sudden change in that intensity at any particular period either of geological or human history. The alteration

in the rate of movement, if it took place at all during our geological history, was as gradual an alteration as the movement itself was always equable and gradual.

The secretion of solid matter from the ocean or the air by animal and vegetable life, and the deposition of that matter as a solid component part of the earth's crust, seems also to have been going on from an indefinite period of past time uninterruptedly down to the present day.

Coral Reefs.—The vast Coral reefs of the Indian and Pacific Oceans, rising from depths of at least 2000 feet, are grand monuments of the duration of this action. Mere centuries seem but units by which to count the time that must have elapsed since the commencement of these great bulks on the coasts of the submerged lands on which they began to grow. Making all allowance for the possibility of rapid growth in reef-making corals, we could not conceive it possible that over a space of a thousand miles in length, a foot could be added to the average height of the reef in less time than several years. Even on the supposition, then, of the slow subsidence of the bottom being continuous, the barrier reef of Australia (as one instance) must have taken several times 2000 years for its formation. But we have in reality no evidence to prove the subsidence of the base and the growth of the upper and outer edge to have been continuous, and it seems to have been stationary for the last 100 years at all events, and may have been so for many centuries; and such pauses in the movement appear rather to be the rule than the exception, so that the more we reflect on it, the more does the date of the commencement of this great reef recede into the haze of past time. And what is true of this single instance is equally true for the atolls and barriers over the space of 6000 miles in the Pacific Ocean. Their very number, too, adds to the length of time that unfolds itself before our reason as a necessity for their formation, since it seems difficult to imagine them all to have begun at once, and the subsidence and upward growth always to have been in action over the whole area at once, and always to have been equal in amount, so as to reduce the time to a minimum. When all the significance of Darwin's explanation of the formation of Coral reefs is taken into account, no one can contemplate his map of their distribution without profound interest. They are the tombstones erected over the buried mountains of a submerged land, of the former existence of which we could have had no suspicion if it had not been for these piles of the skeletons of sea creatures thus heaped upon it during its gradual submergence.

Volcanoes.—If we turn from the Coral reefs and contemplate the extent and distribution of Volcanoes, we have to listen to another version of the same great story. For this purpose, the map given in the Earthquake Catalogue of the British Association, by Mr. R. Mallet, and his son Dr. J. W. Mallet, is a very convenient one.

Beginning in the South Shetland Islands, in lat. 62° south, a chain of volcanoes may be followed through Tierra del Fuego, and along the Andes into Guatemala, and the West Indies and Mexico, and thence along the Cascade Range into Russian America, in lat. 62° north. This is connected by an east and west band through the Aleutian Islands with the Asiatic volcanoes, which, commencing in Kamtschatka in 62° north, may be followed down the Kurile, and Japanese, and Phillipine Islands, to the Moluccas, where they join on to another band, that, commencing on the coast of Birmah, sweeps through Sumatra and Java, Bali, Lombock, and Sumbawa. The two uniting in the Moluccas, run thence along the north coast of New Guinea, and down through the intermediate islands to New Zealand, south of which the line seems to be continued through the Balleny Islands to Mount Erebus and Mount Terror, in lat. 78° south. These two volcanoes, rising to heights of 12,000 feet among the eternal snows of the Antarctic regions, lie between the same meridians of 160° and 170° east, as those of the north of Kamtschatka, so that we have here a sinuous volcanic band, extending north and south through 140° of the earth's polar circumference, or between 9000 and 10,000 miles. If we add the branches, and the American line, this length will be about doubled.

The central volcanic islands of the Pacific, such as the Galapăgos, the Sandwich and Fidjee Islands, and those of the Indian Ocean, have also to be reckoned.

Except the raised coral islands of the Bermudas, and the non-volcanic islands of the West Indies, all the islands of the Atlantic, from Tristan d'Acunha to Iceland, and Jan Meyen Island, are volcanic, and to these we must add the volcanoes of the Mediterranean basin.

The volcanoes of Central Asia are dying out simultaneously, as it appears with the drying up of the waters of the internal basin of drainage, of which the Caspian and Aral Seas are the remains.*

* I do not know that it has ever been remarked that the Mediterranean, and its dependancy the Black Sea, and all the countries the rivers of which flow into these seas, belong in reality to this great internal basin. The current always running in through the Straits of Gibraltar shows that supplies from the ocean are necessary to keep the Mediterranean up to the ocean level. If those Straits then were closed by land ever so little above that level, no overflow would take place out of the Mediterranean, and all Southern Europe and North Africa would belong to the same internal basin of drainage, separate from that of the great ocean, which extends from the neighbourhood of St. Petersburgh to the borders of China. It is remarkable that this internal basin would then be connected in the most intimate manner with the great complex mountain chain of the Old World, running east and west from Spain and Morocco into China. If we regard the Pyrenees and the Atlas as two parallel cordilleras of this chain, we have the table land of Spain, and the western extremity of this basin between them. We must then look to the mountains of Germany and the Valdai Hills of Russia and the Altai mountains of Asia as the northern ranges of this great chain throwing off the drainage of its outer slopes to the Arctic Ocean, and regard the Mongolian and Himmalayah mountains as its eastern and southern borders in Asia, while in Africa that southern border must be extended to the mountains from

Throughout all the vast spaces thus briefly mentioned, there occur volcanic cones, composed of heaps of ejected cinders and ashes, with occasional lava flows, all braced together by injected dykes and veins of lava. These external pustules, symptoms of the internal throes of the more deeply-seated masses of molten rock, have all been accumulated in the same way that we see them now being accumulated. Their present intermittent action, indeed, is obviously but a continuation of that which has been going on from their commencement. We know that many of them have lain dormant for great spaces of time, and then burst forth again into activity.

Vesuvius is but a small example of them, and it must continue for an immense period of time to add to its external size, before it could hope to rival the vastly preponderating bulk of Etna. Yet we know that Vesuvius was dormant for several centuries before our era, and that although it has continued active ever since, yet the subsequent accumulations have not, to say the most, doubled the size of the mountain that existed before the year A.D. 78.

Etna, from all the descriptions of the earliest writers, was very much of the same height and bulk 2400 years ago that it is now, so that Pindar could speak of its being the pillar of Heaven and the nurse of "*everlasting frost*," as well as "containing the fountains of unapproachable fire."—(*Lyell's Princ.*, chap. xxiv.) It bears on its flanks volcanic hills of no inconsiderable magnitude, and Vesuvius might be almost hidden away in the valley called the Val del Bove, that runs down one side of Etna. Its base would cover an English county, and its summit is nearly 11,000 feet high, the whole being made up internally of numerous small cones of ejection buried from time to time under the vast piles of dust and ashes, and the rivers of molten rock that have proceeded from its dominant centre.

If we reckon from what we *know* of the mode of action in the formation of volcanic mountains, taking into account all the pauses which occur between the periods of action, to what date are we to refer the

which the Nile descends. All the high lands between these limits consist of long, but often-interrupted, east and west ranges, together with lofty table lands singularly alternating with deep basins, one of which, that of the Dead Sea, is so greatly desiccated that its waters are now 1300 feet below the ocean level. The Caspian Sea even has shrunk to a depth of 80 feet, and the Mediterranean, and, therefore, the Black Sea would have shrunk had it not been for the supply through the Straits of Gibraltar. Two broad spaces of low land, the one in Russia, between the Carpathian and Ural mountains, and the other in Africa, between the Desert and the Libyan Gulf, seem to lead into this interior basin. Was it formerly connected with the main ocean through these spaces?

When the history of the formation of the countries occupied by this singular complex belt of broken country, which comprises both the loftiest peak and the lowest spots of dry land in the world, comes to be completely written, the connection of this interior basin of drainage with the mountain ranges and table lands will doubtless be found to be an important part of it.

commencement of the ejections which formed the old mountain of Vesuvius as it stood before the time of Pliny? and to what more vast and dim antiquity are we to refer the beginnings of Etna?

But if these two mountains give rise to such unanswerable questions, what shall we say when we come to the general examination of the far larger, far loftier, and still more numerous, volcanic cones which rear their heads along the lines just now spoken of as traversing whole continents and crossing great oceans? The number of cones must be taken into account, because while we know that all the cones of a great district are often dormant together for long periods, we do not know of any instances in which they all become simultaneously active. A great eruption in one is indeed often sympathized with by others, so far as the emission of smoke or slight symptoms of activity are concerned, but no great additions to the bulk of these piles are ever made simultaneously in all.

It is not of course intended to assert that the commencement of all the great active volcanoes of the world dates from a period later than the creation of the human race, though most of them seem to be no older than the existing species of Mollusca. Whatever may have been the dates of their origin, however, their action has been continued through the Recent period and therefore in part belongs to it.

It is clear, also, that since the ejection of these piles, so many of which consist of loose materials, often so pumiceous as to float in water, no natural deluge could have swept over the dry land without leaving evident traces of its passage, neither can the cones have been ever quietly submerged beneath the sea without traces of such an occurrence being discernible.

Movements in the Crust of the Earth.—Earthquakes, which are so commonly the accompaniments or precursors of volcanic eruptions, ought also to be described in our continuation of geological history from human records. They are obviously the external symptoms of the movements generated deep in the earth's crust by the action of the heated interior, when that movement becomes convulsive instead of equable. Mr. Mallet's *Earthquake Catalogue* contains an admirable resumé of their history from the year 1606 B.C. down to the year 1842 A.D. M. Perrey of Dijon continues the account to 1850. No less a number than between 6000 and 7000 separate recorded earthquakes are discussed by Mr. Mallet in the reports attached to his *Catalogue*. During the last four years of his *Catalogue*, he mentions upwards of 400 earthquakes, or an average of about two a week. If, therefore, we allow for many unrecorded shocks which were either too slight for notice or occurred in parts of the earth where no record of them was made, we shall perceive that the crust of the earth is in fact in a perpetual state of vibration and trembling, now in one part,

now in another. If these movements are so often felt even at the surface, it seems that the internal and deeper seated parts of the earth's crust must be still more frequently affected, and by movements of far greater magnitude and intensity than those that reach that surface.

Mr. Mallet discusses the relations of earthquake energy to both time and space, the distribution of earthquakes over the surface of the globe, and their connection with volcanic districts ; he also describes the laws of motion which they seem to observe, comparing them with the vibrations produced artificially by great blasts of gunpowder, and gives rules for finding the depth of the origin of the shock, and directions for observing them more systematically than has hitherto been done.

Conclusion.—These four great actions then—the destruction of rock by chemical decomposition and mechanical erosion,—the formation of rock by chemical or organo-chemical consolidation, and by mechanical deposition—the intrusion of igneous rock from below into or over aqueous rock—and the bodily elevation and depression of different parts of the earth-crust thus elaborated—are still going on now as they have ever done from the earliest periods of geological history. The best account of their recent action will be found in Sir C. Lyell's *Principles of Geology*. Some knowledge of their mode of action now is necessary as a preliminary to the study of their past results, and they were accordingly alluded to in earlier portions of this work, but the geological history of the formation of the crust of the earth would be obviously incomplete without some mention of them in their proper place at the close of the story.

In like manner an account of existing plants and animals, the laws regulating their structure, their classification, their mutual relations, and their geographical distribution, would form a fitting close to the palæontological account of the extinct species of past times. The existing Flora and Fauna that inhabit the globe are the result of the variation and multiplication of species that have been going on uninterruptedly along with the physical changes that have acted on its crust. No violent break in the continuity of the chain of descent, no universal destruction, no sudden end to one population and simultaneous commencement of another, can be proved to have ever happened or even shewn to be probable.

Life, to the fullest extent in number of individuals, and to the utmost variety of forms that circumstances would allow, and with the most far-seeing and omniscient provision for the wants and necessities of the future, has evidently been the all-wise and all-good law of creation, governing both animate and inanimate processes from the earliest geological period down to the present time.

Corrections in the Classification of the Animal Kingdom given at page 376, *etc.*—Since Professor Huxley's tabular classification was printed, I have received from Professor Reay Greene, who is working in conjunction with Professor Huxley, the following improvements of parts of it. In the sub-kingdom Annulosa, the following changes may be made:—

CLASS III.—*Arachnida.*

Order 1.	Pycnogonida .	Nymphon.	Order 5.	Galeodea .	Galeon.
2.	Tardigrada .	Water Bears.	6.	Araneida .	Spiders.
3.	Acarida .	Mites.	7.	Scorpionida .	Scorpions.
4.	Phalangida .	Harvest Men.			

The order 5 Tardigrada? will then be erased from Class V., and from Class VI the Order 7 Rotifera will be removed, and made into Class VII *Rotifera.* In the sub-kingdom Mollusca the name of Class III. may be altered into *Pulmogasteropoda,* and Classes IV. and V. may be made into one class as follows:—

CLASS IV.—*Branchiogasteropoda.*

Sub-Class A.—BR. DIŒCIA.

Order 1. Prosobranchiata . Whelk, Haliotis, Vermetus, Limpet, Chiton.
2. Nucleobranchiata . Carinaria, Atlanta, Firola.

Sub-Class B.—BR. MONŒCIA.

Order 3. Nudibranchiata . Doris.
4. Tectibranchiata . Aplysia, Diphylliia.

The *Conchifera* will then form Class V., and may be divided into

Order 1. Siphonaria . Chama, Cockle, Venus, Pholas.
2. Asiphonaria . . Oyster, Mytilus, Arca, Unio.

The *Brachiopoda* will form Class VI., and the *Polyzoa* Class VII., with the following arrangement:—

ORDER I.—*Phylactolœmata.*

Sub-order 1. Lophopæa . Cristatella, Plumatella.
2. Pedicellinea . Pedicellina.

ORDER II.—*Gymnolœmata.*

Sub-order 3.	Urnatellea	Urnatella.	Sub-order 6.	Ctenostomata	Bowerbankia.
4.	Paludicellia	Paludicella.			
5.	Cyclostomata	Tubulipora.	7.	Cheilostomata	Flustra, Eschara.

In the sub-kingdom, *Protozoa,* the name of the Order Lobosa may be changed into Amœba, and that of Reticularia restored to the better known term Foraminifera.

The Cretaceous Rocks of Greece.—Since the chapter on the Cretaceous period was in the press, I have received, by the kindness of M. D'Archiac, the *Comptes Rendus* for November 11, 1861, in which he gives an account of the observations of M. Gaudry on Attica. From this it appears that Attica is divisible by a line passing through the Piræus into an eastern and western part. The western is little, if at all, metamorphosed, and consists of a thick grey macigno, like the Tertiary Macigno of Tuscany, but covered with wine-red schistose marls alternating with grey limestone and sandstone, and those by 12 to 1500 feet of Hippurite limestone, the whole being believed to be of Cretaceous age. They are much broken and contorted, and form mountains of 4400 feet in height.

In the eastern part of Attica, M. Gaudry believes that it is these very beds that are metamorphosed into the talc schists, mica schists and crystalline limestones to be found there, so that the marbles of Hymettus and Pentelicus are of the age of our Chalk. The old mines of Laurium, of which Xenophon and Strabo speak, and from which the ancients extracted copper, lead, and iron ores, were worked in these Cretaceous rocks.

APPENDIX.

ON GEOLOGICAL SURVEYING.

It has been suggested to me that a few words on the mode of setting to work to make a geological examination of a country would be found useful. Being provided with a large and small hammer, a pocket clinometer and lens, and in some cases a small bottle of dilute acid, the next requisite is to get a good map of the ground to be examined. The scale of the map should be large in proportion to the minuteness and detail of the intended survey. The Ordnance maps, on the scale of six inches to the mile, are in some cases too small for accurate work, but for any amateur work those on the scale of one inch to the mile are generally large enough, and their execution is in all the later maps very good. In foreign countries maps on a much smaller scale have generally to be used, and often very imperfect or inaccurate maps. The north of England too has not yet been completed by the Ordnance Survey, and large parts of Scotland also are still unmapped.

Supposing the observer to be provided with the best attainable map, and to have unlimited time at his command, he may first proceed to make himself acquainted with the geography of the country by traversing it in various directions, viewing it from its hill-tops, and getting a thorough knowledge of its external form. In doing this he must note the lithological constitution of its most prominent rock masses, and determine by the methods pointed out in chapter iii. whether they are stratified and aqueous rocks, or unstratified igneous rocks, or partly of one and partly the other character.

He may then commence his more detailed survey by marking down on his map every exposure of rock on the exact space it occupies, and colouring that space with whatever tint he may select, to denote the lithological or geological character of the rock. If his map be not sufficiently large to admit of this, he must describe the rock in his note-book, with a reference to the exact spot as accurate as he can contrive to make it.

If he find nothing but igneous rocks, he must set himself to determine the different kinds to which they belong, and mark down on his map the area occupied by each. On the Geological Survey carmine is used for Granite, a pale tint for large granite masses, and a darker colour for Elvan dykes and veins. A scarlet colour, composed of carmine and cadmium yellow, is used for Felstones, and all the more purely feldspathic traps, and would be of course used for Trachytic lavas, while a crimson (a mixture of carmine and blue) is used for Greenstone, Basalt, and the basic trap rocks and Doleritic lavas. The varieties of each of these kinds are denoted by letters.

In determining the areas occupied by each kind, the observer will of course note the relations of each to the other, and whether one be intrusive into the other, or what other connection they may have.

In examining stratified or aqueous rocks, the observer will, in the first place, seek for some locality where the best "section" of these can be seen, as described in Chapter XII. The sea coast, or the banks of a river, or an inland cliff, will be most likely to afford him the best natural exposure of the beds; a railway cutting, or a road-side cutting, or a deep ditch, or any other longitudinal trenching of the ground, will give him the best artificial sections. Failing these, he must visit all the quarries or pits of the district, must inquire after all wells and mining shafts, and must get the most accurate accounts he can of the nature of the beds that were passed through, and of their "lie and position," that is to say, the way in which each lay in the ground, and the depth and thickness of each, making particular inquiries as to the "dip" of the beds, or the direction in which they "deepened," and the rate of deepening.

In some districts the rate of deepening is reckoned at so many inches in a yard, or so many feet or yards in a hundred, in others it is stated as a dip of a foot, or a yard, in so many feet or yards.

Geologists usually state the number of degrees at which the beds incline from a horizontal plane.

Table 1 will give the means of translating either of these modes of expression into any of the others, it being understood that the nearest whole numbers are taken, and those figures only given which will be found useful in practice.

The observer will mark on his map by a small arrow the direction of the dip, and write the angle of dip in figures alongside the arrow, or he will enter the information in his note-book to be transferred to a map subsequently if necessary.

In any operation requiring greater exactness, more accurate instruments than a pocket clinometer will of course be used, and the calculations be made accordingly.

Table I.

Shewing different modes of stating the Dip.

In this table, only those numbers are given which are likely to be found of use in practice, and that chiefly to the nearest whole number, omitting fractions.

Angle of Dip.	Incline of	Ft. or Yds. in 100.	Inches in a Yard.	Angle of Dip.	Incline of	Ft. or Yds. in 100.	Inches in a Yard.
1°	1 in 57	1¾	0½	30°		58	21
2°	1 in 29	3½	1	35°		69	25
3°	1 in 19	5½	2	40°		83	30
4°	1 in 14	7	2½	45°	1 in 1	100	36
5°	1 in 11	9	3	64°	2 in 1		
6°	1 in 10	10	4	72°	3 in 1		
7°	1 in 8	12½	4½	76°	4 in 1		
8°	1 in 7	14	5	79°	5 in 1		
9°	1 in 6	16	6	81°	6 in 1		
11°	1 in 5	20	7	82°	7 in 1		
14°	1 in 4	25	9	83°	8 in 1		
18°	1 in 3	33	12		etc.		
20°		36	16				
24°		44	17				
26°	1 in 2	50	18				

In highly inclined rocks dipping in different directions the amount of dip varies so frequently that minute accuracy in observing it is often waste of time; but the strike of the beds, and their course across the country, should be carefully observed.

When the surface of the ground is very uneven, the observer must recollect that the strike of the beds will not correspond with their line of outcrop on the map, or will only correspond with it on the great scale, that is, when the length to which the bed may be traced is very large compared with the undulation of the surface. When the angle of dip is low, a comparatively small undulation of the ground will, of course, cause the outcrop of a bed to deviate widely from the line of its strike: and, on the other hand, a slight change in the strike, or in the amount of the dip of a bed, will produce a much greater effect than when the inclination of the dip is a high one.

The observer must endeavour to keep in his mind the ascertained thickness of the group of rocks he is tracing, and all their possible

changes in dip and strike, and the consequent relations of these to the different features of the surface, so as to guard himself against being deceived or led astray.

He must also not spare his own labour, but search diligently every square yard of ground on which there is any possibility of rock being exposed, so that he may be sure of being acquainted with every observable fact before he draws his conclusions. If time or the means at his disposal do not allow of his survey being thus exhaustive, he must always entertain a certain amount of diffidence in the conclusions he arrives at, and hold them open to future correction.

If he find in tracing stratified rock that the appearances are such as to render probable the existence of a fault or dislocation, he must be particularly on his guard against allowing his mind to jump to the conclusion that it exists, before he has put that existence beyond doubt.

Faults or dislocations are doubtless much more numerous than we are aware of, but for that very reason great care should be taken not to introduce them on geological maps except in the precise situations and with the precise directions which they really hold. I speak in this matter from personal experience, and with an ample measure of remorse for my own sins in this matter. It is the error into which many geologists most easily fall, and which they ought to be most warned against for the future. Most especially should the greatest caution be exercised before the first dislocation is laid down in a district. If one line of fault be proved beyond all question to exist, others must almost necessarily be present, either parallel to it, or more or less nearly at right angles to it. Before one fault then be laid down, the observer should require an amount of evidence which can allow of no other possible solution than the fact of a dislocation, but having proved that, and having accurately determined its direction, a much less amount of evidence may be reasonably admitted for the existence of the corresponding dislocations. Even when, in making observations in mining districts, he is assured of the existence of a fault by the miners themselves, the observer must be on his guard, and carefully ascertain that by a "fault" the miners mean really a "dislocation," and that their statements as to its "throw" or its "width" are such as he clearly understands, and are correctly stated by the men themselves.

Keeping these precautions in his mind, the observer may, from detached observations, lay down on his map the boundary line between two different sets of beds with more or less accuracy, according to the number of his "data," or in other words, the number of places in which the rocks are clearly exposed.

By drawing the upper and lower boundary of a set of beds, and observing their average inclination, it is obvious that he can calculate their thickness; and by doing this for the outcrop of several sets of

beds, he can determine approximately the depth at which the lower set will be found under any given spot of the upper. For this purpose he must assume the surface of the ground to be a plane, and then if necessary measure its undulations, and allow for any departure from the true plane. The thickness of the beds whose outcrop has been traced, or the depth attained in a given horizontal distance by any one of them, may be learnt either by protraction and measurement or by calculation.

The following table will save trouble in most instances; the thickness measured at right angles to the dip, and the depth measured at right angles to the horizon, being given for every degree up to 20° and for every 5° after that, that will be attained for every distance of 100 (feet, yards, etc.), measured horizontally directly across the strike of the beds:—

TABLE II.

Depth and Thickness Table.

Horizontal distance = 100.*

Angle of Dip.	Depth.	Thickness.	Angle of Dip.	Depth.	Thickness.
1°	1·7	1·7	18°	31·8	30·9
2°	3·5	3·5	19°	34·5	32·6
3°	5·3	5·3	20°	36·6	34·2
4°	7·0	7·0			
5°	8·8	8·7	25°	46·9	42·3
			30°	58·0	50·0
6°	10·6	10·5	35°	70·5	57·4
7°	12·3	12·2	40°	84·2	65·6
8°	14·1	13·9	45°	100·0	70·7
9°	16·0	15·6			
10°	17·7	17·4	50°	119·0	76·6
			55°	143·0	81·9
11°	19·5	19·1	60°	174·0	86·6
12°	21·4	20·8	65°	214·0	90·6
13°	23·2	22·5	70°	275·0	94·0
14°	25·2	24·2			
15°	26·9	25·9	75°	368·0	97·0
			80°	575·0	98·0
16°	28·7	27·6	85°	1143·0	99.0
17°	30·7	29·2			

As this table is one giving the solution of a right-angled triangle for each angle specified, it may be used to find any dimension which

* It is sometimes more convenient to consider the horizontal distance 1000, when the decimal point in the table disappears, and the numbers given become 17, 35, 53, etc., instead of 1·7, 3·5, 5·3, etc.

can be stated in the form of a right-angled triangle, as for calculating the space between the outcrop of two beds of which the angle of dip is known, and the thickness between them; the distance which any bed, of which the depth and inclination are known, will require before its outcrop at the surface can occur; and so on.

By means of this table, also, the probable "throw" of faults can be ascertained, where the broken ends of a bed on opposite sides of a fault can be found, and a certain mean angle of dip assigned to the whole mass. If, for instance, there be a set of beds, including one particular bed A B C, which are traversed by a fault F F either at right angles to their strike, or obliquely as drawn in the fig., and the mean dip of the beds be 30°, and the outcrops of the broken bed A B C be found on opposite sides of the fault in such a position that the strike of the piece B C which is "upthrown," (when produced if the fault be oblique so as to be measured at right angles to A B), be found to be 150 yards (or any other distance) apart from the strike of the "downthrown" piece; then, as the table will give us the depth which the downcast piece has attained at the distance of 150 yards, and the depth accordingly which it has on one side of the fault, while the upthrown piece crops out exactly on the other side of the fault, that depth is of course the "throw" of the fault. If it be 100 yards, then, with a dip of 30°, the table shews a depth of 58 yards, which is the amount of the downthrow; if 150 yards, it will of course be $58 + \frac{58}{2}$ (or 29) = 87; if 200 yards, it will be 116, and so on; and if the dip had been 12°, and the horizontal distance 100 yards, then the throw would be 21·4 yards; if 1000 yards, the throw would be 214 yards, and so on.

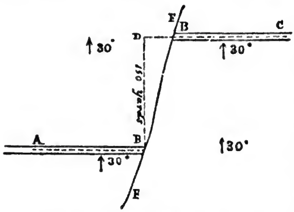


Fig. 124.
To illustrate calculation of throw of fault by table.

* The table is indeed of continual use to the practical geologist, in checking his preconceptions as to depth and thickness, amount of dislocations, etc. etc. etc.

Construction of Sections.—The formation of a geological map, by joining together the separate appearances of the outcrop of beds at the surface, is only a part of the work necessary to convey a knowledge of

* Messrs. Troughton and Simms of Fleet Street, London, have prepared, at my suggestion, a little ivory protractor, on which this Table and part of Table I. are engraved, together with the scales of the six-inch and one-inch maps, which the observer will find very useful to have in his note book or map case. Its price is 10s.

the geological structure of a country. This map may often be taken as a horizontal section of the district, formed by cutting it by a horizontal plane at a certain level, and removing all the matters above that plane. In order fully to understand, however, the "lie and position" of the rocks, it is necessary to have a vertical longitudinal section which shall shew the direction and amount of their inclination beneath the horizontal plane, and the depth attained by any particular bed under any spot at a given distance from its outcrop. For this purpose a horizontal datum line is assumed, which is generally the level of the sea, and a line of country selected for the section which is generally taken at right angles to the strike of the beds. The undulations of the ground along the selected line are then marked in, so as to give the proper heights for the different points above the assumed datum line. If the scale for horizontal and vertical distances be the same, the result will of course give us a true profile or outline of the features of the ground. This, however, often requires the section to be drawn, either to such a great length as to be unmanageable, or on such a small scale that the vertical distances are too minute for distinctness. It is in such cases advisable to sacrifice the correct outline and enlarge the heights to several times their due proportion, which of course involves a corresponding distortion in the angle of inclination of the beds and their apparent thickness, and so on. If, however, the two scales be given, it is easy, of course, to correct the apparent distortion by calculation and measurement, and learn the true facts from the section. Having got the outline of the ground, we must then insert in their proper places the outcrop of the different beds and formations, or masses of igneous rock, faults or veins, etc., as noted on the map or in the observations in the note book, and draw them at their proper angle if the section be on the natural scale, or at a calculated angle if it be distorted. This calculation can easily be made from Table II. by ascertaining what depth any bed, etc., would reach in any given horizontal distance at the real angle, and drawing them so as to be at that depth at that horizontal distance in the distorted section.

When a section is drawn across a greatly disturbed district, parts of it will almost of necessity be drawn, not directly across the strike of the beds, or with their dip, but more or less obliquely to it. Sometimes the section might unavoidably run along the strike of the beds for some distance, if so, the beds will of course appear to be horizontal in that part of the section, since they will dip either directly from or directly towards the spectator, and will therefore incline neither to his right nor to his left hand. When the section runs directly across the strike, it will of course represent the true dip of the beds. If it go obliquely across the strike, then it will represent the dip at some intermediate angle between the horizontal line and the

true dip. As the calculation of the proper correction to be made for this obliquity in the line of section is rather troublesome, and as in some instances it is advisable that it should be given correctly, not only for the purpose of determining the depth of beds, but also for drawing the true angle of lines of faults, joints, veins, dykes, and cleavage planes, the following table is added. This is taken from one which I constructed for my own use when running sections in North Wales, but the nearest whole numbers are only stated in it, and the lower degrees of dip and obliquity omitted, as neither they nor the minutes of degrees are practically useful.

Table III.

Oblique Section Table.

Angle between the direction of the dip and that of the section.	Angle of the Dip.										
	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.	Degs.
Degs.	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**89**
40	32	37	42	47	53	58	64	70	77	83	88
45	30	35	40	45	51	56	62	69	76	83	88
50	28	32	37	42	48	54	60	67	74	82	88
55	25	29	34	39	45	51	57	65	73	81	88
60	22	26	31	35	41	47	54	62	70	80	88
65	19	23	27	31	36	42	49	57	67	78	87
70	16	19	22	26	30	36	43	52	63	75	87
75	12	14	17	20	24	29	35	44	56	71	86
80	8	10	12	14	17	20	25	33	44	63	84
85	4	5	6	7	8	10	13	18	26	45	79
89	1	1	1	1	2	2	3	4	5	11	45

Note.—This table, in a fuller form, is given in the Appendix to the Geology of the South Staffordshire Coal-field.—(*Mems. Geol. Survey.*)

The angles stated in the first column are those between the direction of the line of section and that of the dip of the bed, fault, vein, cleavage plane, or other inclined line that is to be inserted in the section. This insertion can be correctly made (in a section on the natural scale), by seeking in the table the number which will be found at the intersection of the requisite horizontal and vertical columns.

If, for instance, a section be drawn along a line which crosses the line of dip at 55°, and the beds at one part dip at 65°, they would be represented as they would be seen in a natural vertical cliff if one ran along that line of section, by drawing them at an angle of 51°. If they changed their strike a little farther on, so that the straight line of section crossed their new dip at an angle of 75°, their apparent dip should be reduced to 29°, giving them the requisite curve between the two dips at the part where the beds curved their strike.

The "angle between the direction of the dip and that of the section" is always to be calculated on that side of the section where the angle between them is less than 90°, and the direction of the dip in the section is to be drawn accordingly. If, therefore, the angle between them be large, and the direction of the section be slightly changed at one point, so as to shift the side on which the lesser angle lies, the apparent dip in the section will have its direction changed, although no change has taken place in reality. Suppose, for instance, the cleavage planes in a certain tract of country dip due N. at 80°, and a section be taken across that ground in a direction from W. 5° S. to E. 5° N. up to a certain point, the spectator being supposed to be looking towards the north, the angle between that section and the dip of the cleavage planes being 85°, they will be drawn in the section as dipping at 26° to the east or towards the spectator's right hand. If, however, the direction of the section be changed at that point, and it be continued on a line from W. 5° N. to E. 5° S., the direction of the dip of the cleavage planes must of course be altered, and they must be drawn as if dipping at 26° to the west, or towards the spectator's left hand. It is obvious that this would be their appearance if two real cliffs were to be formed running in the directions above named, and meeting in a corner at an angle of 170°. The cleavage planes would go straight across from the one to the other, and would rise from the base towards the summit of the cliff on either hand of the spectator, or dip from the summit, towards the foot of the cliff, on each side of the spectator as he looked northwards towards the junction of the two cliffs.

It must be recollected, that if the section be not drawn on a natural scale, but on two scales differing in height and length, the dip must first be drawn with the requisite amount of exaggeration, as before described, and then that must be measured and the proper correction applied to it if the line of section be oblique to it. This, however, will not often be required except in mining sections.

One error to be guarded against in constructing sections is the very natural one of supposing that all the intermediate pieces of ground, between the parts where the outcrops of the beds are to be seen, are occupied by beds dipping at the same angle, or even in the same direction, as they do in those parts. It may happen that the outcrop

of beds is visible only in those places where they are more highly inclined than usual. It may even be the case that only those parts which dip in one direction are visible, while the intervening concealed parts dip in another direction. Very serious errors have in this way crept into many sections published by even high authority. It is, however, one that should be strenuously guarded against, for which purpose the sections lately published by the Geological Survey in Ireland have only those beds engraved on them which are certainly known to exist, the intermediate spaces being left blank, and as far as possible omitted in the calculations for thickness.

The student may be often at a loss to find the real heights of the places his section passes over, as levelling is a troublesome and sometimes expensive operation. The Aneroid Barometer will often assist him in determining the highest and lowest points of his section with comparative facility. If, however, this be unattainable, he will almost always be able to learn the height of some of the canals, railways, or roads, or the height of some river or other object in his neighbourhood, from which the altitude of other points may be estimated with sufficient accuracy for his purpose. If he once get the height of any point in the main river of a district, he will know that no piece of ground from which the water flows towards that point can be at a lower level than it, and will thus get a limit in that direction for the depth of his undulations, while the altitude of the highest hill in his district will give him a limit in the other direction, and by constantly referring to these two he will generally be able to construct a geological section with sufficient approximate accuracy for ordinary purposes. An error of twenty or thirty feet will be of no real importance to him, when he recollects that in his section it is probably included in the breadth of a pencil line.

Sections for practical operations, such as mining or engineering, or in those cases where important conclusions are to be drawn from the relative heights of particular points, are of course to be treated on quite different principles from those geological sections which are often only diagrammatic representations of the general facts as to the superposition of groups of beds, useful to ascertain only their average thickness or to point out their mode of occurrence beneath the surface.

INDEX

NOTE.—In the following Index, an attempt is made to unite to some extent an index, a dictionary, and a "gradus." The Greek words have the explanation only added in italics; those derived from other languages have their source pointed out. Among the palæontological terms, it is not always easy to find out what the idea was in the mind of the describer, and what Greek words the name is derived from. Some words have quite baffled any research I was able to make, and others remain doubtful. Another source of difficulty in discovering these derivations is the difference of the letters adopted in writing the Greek and Latin alphabets. The Latin "c" seems to have been always used as the equivalent of the Greek "k." It appears that the Romans pronounced Cicero and Cæsar as Kikero and Kaesar. The Greek "u" is in like manner always written "y" in the Roman alphabet. Perhaps we find a clue to this custom in the Welsh language at the present day, where the words "cy," *a dog*, and "du," *black*, are pronounced as if spelt "kee," and "dee;" and the word "dyffryn," *a valley*, is pronounced as if spelt "duffrin." The Romans having confounded the Greek long and short *o* and the long and short *e*, each under one letter, is another cause of difficulty in detecting the Greek words in a Latin dress, more especially where the composition of two or more words is irregularly made. In some words also the Greek aspirate has been omitted, apparently from inadvertence, as it is only marked by an inverted comma, and not by a separate letter. It is pretty certain that not only was the *c* always pronounced as *k*, but that the Greeks, and probably the Romans, never used the soft sound of "ch" or of "g," and that in Greek words these letters should always be hard. Nobody, however, would now like to be guilty of the pedantry of pronouncing geography with a hard initial g. Custom in this, as in other cases, gives us the decision and law for speaking.

I have been in some doubt as to the proper quantity of the "i" in the termination "ites," as if it be derived from "lithos," as is commonly said, it would seem necessarily short; it appears, however, that in the Greek word "purites" or "pyrites," the *ī* was long, and that may be taken as a guide for other words. Where the word lithos is preserved entire, as in graptolithus, it should obviously retain the quantity of the original.

I believe, on the other hand, that the termination "ide" or "ides," signifying a group or family, should have the "i" short. J. B. J.

* "Pholis" refers to the "scute" or scale of a reptile; and "lepis" to that of a fish.

* Hyrax is the Greek name for the shrewmouse; it is now given to a small perissodactylian. See p. 377.
† Trigŏnus means *of the third generation.*

* See note, p. 738.

* Properly Rhaphsiosaurus and Rhaphiostoma.

* Thrissas is the Greek name for a fish.

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